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of

THE ROYAL AERONAUTICAL SOCIETY

SEPTEMBER 1961

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None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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Note: Under the revised By-Laws, allowed on 11th January 1960, the President of each Division and the Chairman of each Section of the Society is a Member of Council by reason of his office.

THINGS TO COME ARE HERE

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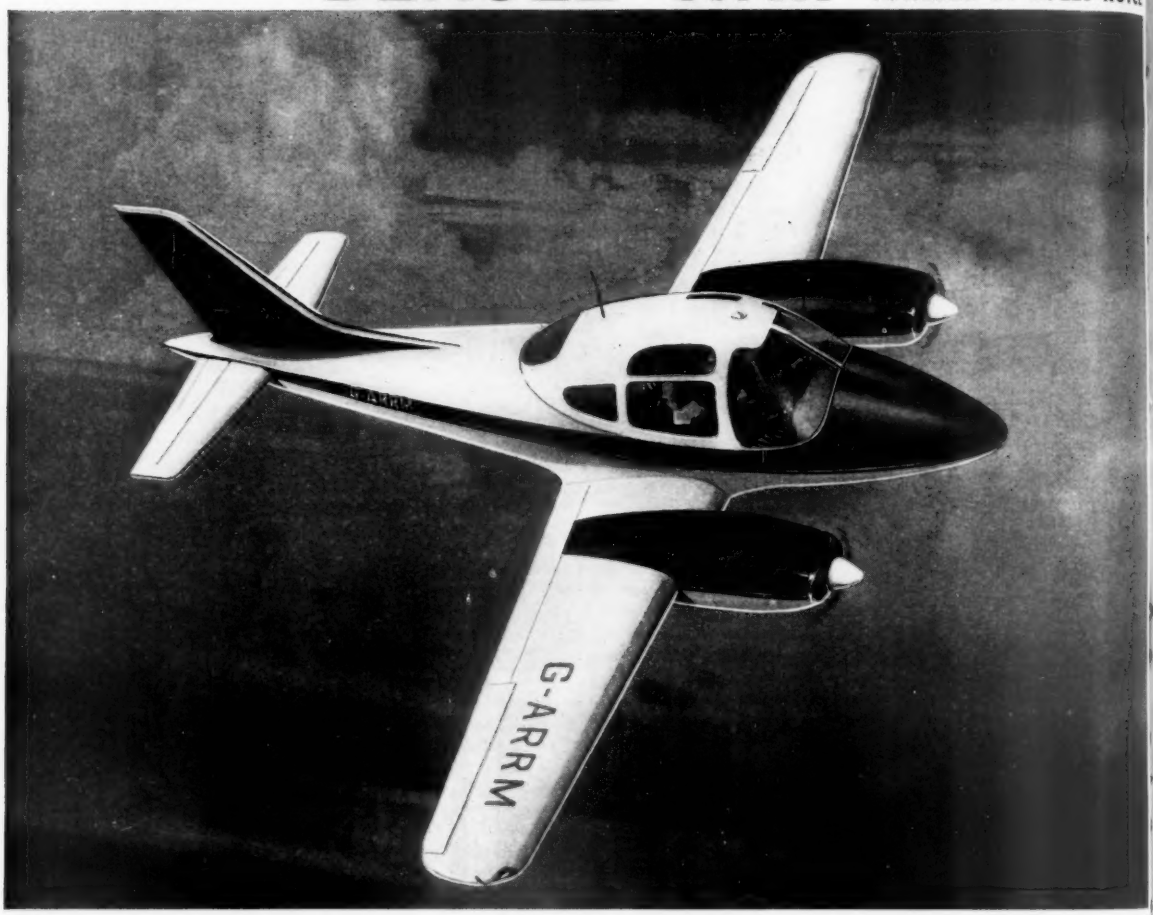

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NOTICES

Eighth Anglo-American Aeronautical Conference London, 3rd-14th September 1961

The Eighth Anglo-American Aeronautical Conference convened by the Society, the Institute of the Aerospace Sciences and the Canadian Aeronautical Institute, opened in London on 3rd September with a reception for all delegates and their ladies by the President and Council at 4 Hamilton Place. During the first week of the Conference visits have been arranged for delegates from Canada and the United States to the S.B.A.C. Display at Farnborough, the Industry and Research Establishments. A special programme of visits and entertainment during the Conference has been arranged for ladies accompanying delegates.

The technical sessions, which will all be held in the Lecture Theatre, will begin on 11th September.

The Offices of the Society will be open for registration of delegates from 2.00 p.m. - 8.00 p.m. on Sunday 3rd and on Sunday 10th September.

The following is the Conference Programme.

Sunday 3rd September

Reception, 6.00 -8.00 p.m., 4 Hamilton Place.

Monday 11th September

9 a.m. - 10.30 a.m.	Meteorological Measurements from the Tiros Satellites—W. G. Stroud (Goddard Space Flight Center, N.A.S.A.).
11 a.m. - 12.30 p.m.	On the Attitude Control of Earth Satellites—E. G. C. Burt (Royal Aircraft Establishment).
2 p.m. - 3.30 p.m.	Upper Atmosphere Experiments with Particular Reference to Black Knight and Skylark—Sir Harrie Massey (University College, London).
4 p.m. - 5.30 p.m.	Communications Satellites—George E. Mueller, W. B. Hebenstreit and E. R. Spangler (Space Technology Laboratories Ltd.).

Tuesday 12th September

9 a.m. - 10.30 a.m.	Ground Proximity Effects Associated with V/STOL Aircraft—John P. Campbell (Langley Research Center, N.A.S.A.).
11 a.m. - 12.30 p.m.	Some Considerations in Selecting VTOL Propulsion Systems—A. P. Adamson and D. Cochran (General Electric Co., Flight Propulsion Laboratory).
2 p.m. - 3.30 p.m.	The Inverted Turbojet—Dean D. L. Mordell, F. W. Eyre and A. V. Sreenath (Department of Mechanical Engineering, McGill University).
4 p.m. - 5.30 p.m.	Aerodynamic and Propulsion Considerations of Minimum-Field Aircraft—P. L. Sutcliffe and V. K. Merrick (Hawker Siddeley Aviation Ltd.) and A. R. Howell (National Gas Turbine Establishment).
Evening, 7 p.m.	49th Wilbur Wright Memorial Lecture. Researches in Space Flight Technology—Dr. Abe Silverstein (N.A.S.A.). Followed by a Reception. *See* Special Notice.

Wednesday 13th September

9 a.m. - 10.15 a.m.	Transports of the Future — A Systems Approach — George Prill and Harold D. Hoekstra (Federal Aviation Agency).
10.30 a.m.-11.45 a.m.	The Influence of Some Operational Problems on Supersonic Air Transport—R. G. Thorne (Royal Aircraft Establishment).
11.45 a.m. - 1.00 p.m.	The Supersonic Commercial Air Transport Requirements and Problems — John Stack (Langley Research Center, N.A.S.A.).

Thursday 14th September

9 a.m. - 10.30 a.m.	General Aspects of Supersonic Transport Aircraft—Dr. A. E. Russell (Bristol Aircraft Ltd.).
11 a.m. - 12.30 p.m.	On the Nature of Aerofoil Characteristics with a Sink Located in the Upper Surface — Comparison of Theory with Some Fan-in-Wing Experiments—D. C. Whittley and J. R. Bissell (Avro Aircraft Ltd.).
2 p.m. - 3.30 p.m.	Looking Ahead in V/STOL—G. S. Schairer (The Boeing Company).
4 p.m. - 5.30 p.m.	Control of VTOL Aircraft—J. J. Foody (Short Bros. and Harland Ltd.).
5.30 p.m. - 6.00 p.m.	Concluding remarks by the three Presidents.
Evening	Conference Dinner-Dance.

Wilbur Wright Memorial Lecture—and Reception Tuesday 12th September

The Forty-ninth Wilbur Wright Memorial Lecture, "Researches in Spaceflight Technology," will be given during the Eighth Anglo-American Aeronautical Conference by Dr. Abe Silverstein, F.R.Ae.S., F.I.A.S., Director of Space Programs, N.A.S.A., on **Tuesday 12th September** (not Thursday as stated in the August Journal) at **7 p.m.** in the Lecture Theatre, 4 Hamilton Place. The main honours and awards of the Society for the year will be presented before the Lecture.

The lecture will be followed by a Reception and Buffet Supper (8.30-10.30 p.m.) at 4 Hamilton Place, which will be open to **all** members of the Society and their ladies, whether or not they are attending the Conference. Tickets for the Reception, price £1 5s. 0d. each, may be obtained from the Society, 4 Hamilton Place.

Fellowship

The following have been elected to Fellowship:—

Eric Sydney Allwright, Assistant Chief Engineer (Aircraft), Vickers-Armstrongs (Aircraft) Ltd., Weybridge.

Reginald Percy Dickinson, Superintendent of Performance Division, Ministry of Aviation, A. & A.E.E., Boscombe Down.

George James Thomson, Chief Technical Engineer, Westland Aircraft Ltd., Saunders-Roe Division, East Cowes.

First Annual Lecture of the British Conference on Automation and Computation

Dr. D. G. Christopherson, O.B.E., F.R.S., Pro-Vice-Chancellor of the University of Durham and Warden of the Durham Colleges, will give the First Annual Lecture of the British Conference on Automation and Computation (B.C.A.C.). The Lecture, entitled "Mathematics—Friend or Foe?" will be given in the Lecture Theatre of The Institution of Electrical Engineers, Savoy Place, London, W.C.2, on Wednesday 27th September, at 5.30 p.m. (Tea at 5.0 p.m.). The lecture is open to all members of the 31 member societies of B.C.A.C.; others should apply for tickets (free) from the Honorary Secretary, B.C.A.C., c/o The Institution of Electrical Engineers, Savoy Place, London, W.C.2.

DIARY

MAIN SOCIETY

All lectures in London will be held in the Lecture Theatre, 4 Hamilton Place, unless otherwise stated.

3rd-14th September
EIGHTH ANGLO-AMERICAN CONFERENCE.

12th September
49TH WILBUR WRIGHT MEMORIAL LECTURE—Researches in Spaceflight Technology. Dr. Abe Silverstein. **7 p.m.** To be followed by a Reception, *see special notice.*

25th-29th September
Symposium—Crack Propagation. To be held at the College of Aeronautics, Cranfield. *See notice in August* JOURNAL.

11th October
AGRICULTURAL AVIATION GROUP—Agricultural Aviation in New Zealand. G. G. Lindsay. **7 p.m.**

12th October
MAIN LECTURE at the Isle of Wight Branch. Experiences in Constructing and Flying Bell's Recent VTO Aircraft. J. O'Malley, Jr. **Saunders-Roe Club House,** East Cowes. **6 p.m.**

19th October
FIFTH LANCHESTER MEMORIAL LECTURE—From Ship Accompanying Waves to Shock Waves of Supersonic Aeroplanes. R. Legendre. **6 p.m.**

30th October
HISTORICAL GROUP—Lecture by Sir Frederick Handley Page. **6 p.m.**

ASTRONAUTICS AND GUIDED FLIGHT SECTION

16th October
Packaged Liquid Rocket Propulsion Systems. W. N. Neat and K. G. Page. **6 p.m.**

GRADUATES' AND STUDENTS' SECTION

27th September
Film Show. **7 p.m.**

ROTORCRAFT SECTION

6th October
Integrated Flight Systems for Multi-Engined Rotorcraft Transports. N. Sullivan and J. A. Simpson and an American representative. **6 p.m.**

BRANCHES

20th September
Coventry—Fire Precautions in Aircraft. J. B. Sheldon. Herbert Art Gallery. 7.30 p.m.

2nd October
Derby—The SC.1. D. Keith-Lucas. Rolls-Royce Welfare Hall, Nightingale Road. **6.15 p.m.**

3rd October
London Airport—The DH 121. J. P. Smith. Senior Mess Club, B.O.A.C. H.Q. 6 p.m.

10th October
Luton—Film Evening. Napier Senior Staff Canteen, Luton Airport. 6 p.m.

12th October
Isle of Wight—Main Society Lecture. Experiences in Constructing and Flying Bell's Recent VTO Aircraft. J. O'Malley, Jr. Saunders-Roe Club House, East Cowes. 6 p.m.

BRITISH ASSOCIATION GRANADA LECTURES

The 1961 Series of three lectures organised by the British Association and sponsored by Granada TV Network on "Communication in the Modern World" will be held at Guildhall, London, on 3rd, 12th and 17th October as follows:

3rd Oct.	The Language of Animals, by Sir James Gray, C.B.E., M.C., F.R.S.
12th Oct.	Why Scientists Talk, by Professor Hermann Bondi, F.R.S.
17th Oct.	The Gap—and The Bridge, by Sir John Wolfenden, C.B.E. This lecture will deal with communication between the scientist and the humanist.

Members should apply for tickets for these lectures to: Granada TV Network, Golden Square, W.1.

ACKNOWLEDGMENTS

The Council wishes to thank the donors for a fine specimen of a four-bladed propeller with the inscription "1917 12 cyl. R.A.F. 4A 40 H.P. R.E.8 T6296."

The Council also wishes to thank C. H. Gibbs-Smith, Esq. (*Companion*), for photostat copies of "Memoire sur le vol artificiel" by Sir George Cayley and "Subject List of Works on Aerial Navigation and Meteorology in the Library of the Patent Office—1905."

The Council also thanks Commander F. W. N. Bassett (*Assoc. Fellow*) for the return of back numbers of the JOURNAL.

The Council thanks Alitalia Italian Airlines for the gift of ten Commemorative Airmail Covers flown on the inauguration of the DC-8 on their services.

SUMMER CONFERENCE ON NON-DESTRUCTIVE TESTING: 21ST-23RD SEPTEMBER 1961

The Non-Destructive Testing Society of Great Britain is holding a Summer Conference at the Blossoms Hotel, Chester, from 21st-23rd September 1961. The theme will be "Industrial Radiology Today" and papers and discussion will be based on newly developed aspects of Industrial Radiology. The subjects covered will include low KV radiography, Xeroradiography, linear accelerators, Betatrons, large gamma ray sources for radiography and current safety regulations. The Conference is open to all who are interested, whether Members of the Society or not, and the fee will be 15s. 0d. for Members and £1 10s. 0d. for non-Members. Further details and application forms may be obtained from the Conference Secretary, Mr. I. M. Barnes, Materials Laboratory, de Havilland Aircraft Co. Ltd., Manor Road, Hatfield, Herts.

ELECTIONS

The following is a list of elections and transfers of membership of the Society:—

Associate Fellows

Emmanuel Berg (*ex Student*)
George Barry Bolland (*from Graduate*)
Cecil Maxwell Cade
Bernard Fitzgerald Collins (*from Associate*)
Robin Michael Dakin (*from Graduate*)
Roland Michael Fitzgerald
Ian Bevill Hudspith
Brian Arthur Kerry (*from Graduate*)
Richard Penderell Llewelyn (*from Graduate*)
George Alfred Bertram Lord (*from Associate*)
Francis Ernest Osborne
David Henry Pepper
Colin Rodgers (*from Graduate*)
Kenneth Roy Sherhod (*from Graduate*)
Bernard Albert Ward

Associates

John Frank William Crane
Stanley Hauxwell
James Barrie Hogg
George William Brian Lacey
William Frodsham Pritchard (*ex Student*)
Jan Patcha
John Nathaniel Somers
Peter Ward

Graduates

Roberto Maria Cajal
Alan Charles Eagles
Benjamin Halman
John Bruce Howard (*from Student*)
Donald Frederick Charles Lamb (*from Student*)
Russell Allan Loxley (*from Student*)
Alexander Lucas
John Patrick McNulty
David Morton (*from Student*)
Ronald Aron Mosberg
George Wotherspoon Swan
Gordon Agar Wardill
Stephen Archibald Whymark

Students

Brian Harry Bickers
John Henry Cox
Michael Henry Davis
Neil Forrest
Harbans Singh Ochani
John Henry Riddle

Companions

Evgeni Alfkseevich Smirnoc

Refresher Courses at Ecole Nationale Supérieure de l'Aéronautique

The Ecole Nationale Supérieure de l'Aéronautique is organising special refresher courses of lectures during 1961-62 for aeronautical engineers. These courses, which are open to foreign applicants, will cover five main subjects:—(1) Modern mathematical methods, (2) Automatics applied to aeronautics, (3) Thermo-Aerodynamics, (4) Materials and (5) Electronics and radio techniques. The courses will enable engineers to obtain the diploma of "Maître ès Sciences Aéronautiques."

Full particulars of the courses and of the costs may be obtained from E.N.S.A., 32 Boulevard Victor, Paris XV^{e}.

University College London Courses on Air Law, 1961-62

The Faculty of Laws at University College, London, maintains two courses on International and Comparative Air Law for non-degree students. The lectures are given once a week in the evening. The first year course deals with the General Principles of International and Comparative Air Law: Introduction, the Right to Fly, the Legal Régime of Flightcraft, the legal Régime of Crew, Passengers and Cargo, Airports and other Navigation Facilities, Rules of the Air and Air Traffic Control, Air Transport and Carriage by Air, Liabilities Arising from the Operation of Aircraft and Air Services, Insurance, International Law in time of War, Institutions and Organs for the Creation and Administration of Air Law. The second year course covers Selected Problems of the subject on a more advanced level: International Air Transport Agreements, Liabilities of Operators of Aircraft, Conflict of Jurisdiction and Choice of Laws. The fee for each of the two courses is £13 10s. 0d. per Session and the Registration Fee is £1 0s. 0d. Further details and application forms may be obtained from the Faculty Office (Miss L. G. Taylor, telephone Euston 7050, ext. 488) University College, London, Gower Street, W.C.1.

Symposium on "Some Aspects of Vacuum Science and Technology": 5th January 1962

The Institute of Physics and the Physical Society will hold a one day symposium on "Some aspects of vacuum science and technology", at Imperial College of Science and Technology, London, on 5th January 1962. The scope of the symposium will be: (*a*) continuously exhausted bakeable vacuum apparatus for pressures below 10^{-9} mm. of mercury and (*b*) the controlled deposition of evaporated film. Further details and application forms will be available about the end of October 1961 from the Administration Assistant, The Institute of Physics and The Physical Society, 47 Belgrave Square, London, S.W.1.

News of Members

C. A. Bates (*Associate*) formerly Chief Inspector Hordern-Richmond Ltd., is now Group Chief Inspector Permali Ltd. and Hordern-Richmond Ltd., Gloucester.

E. Bedford (*Associate*) a member of Council of the Southern Africa Division and formerly Aviation Representative in Southern Africa for Vickers-Armstrongs, is now with Vacuum Oil Co. Ltd., and has been appointed Aviation Sales Representative.

Sqn. Ldr. W. A. Beedie (*Associate Fellow*) formerly at R.A.F. Technical College, Henlow, has been posted to the Royal Aircraft Establishment (Guided Weapons Department).

Sqn. Ldr. C. B. Bolton (*Associate Fellow*), R.A.F., formerly O.C. Provost Servicing and Ground Support Squadron at R.A.F., Linton-on-Ouse, Yorkshire, is now at The Human Engineering Division, R.A.E., Farnborough.

The Rt. Hon. Lord Brabazon of Tara (*Hon. Fellow*) has accepted the invitation of the Minister of Aviation to become the Chairman of the Air Safety Board.

Engineer with Associated Electrical Industries Ltd., N. J. Carew (*Associate Fellow*) fomerly Mechanical Coventry, is now Senior Research Engineer, Mechanical Department, Research Division, Brush Electrical Engineering Co. Ltd., Loughborough.

D. F. Carey (*Associate*) formerly A.I.D. (M.O.A.), Nottingham Group Office, is now Tech. Grade I, A.I.D., at Bristol Siddeley Engines Ltd., Bristol.

Sqn. Ldr. C. H. W. Champness (*Associate*) has retired from the R.A.F. and is now Programme Engineer in the Design Office of Vickers-Armstrongs (Aircraft) Ltd.

D. F. Cook (*Associate*) formerly with Blackburn Aircraft Ltd., is now a Senior Aerodynamicist with Hunting Aircraft Ltd., Luton.

K. G. Draper (*Associate Fellow*) formerly Senior Stressman, Teleflex Products Ltd., Basildon, Essex, is now Chief Stressman with Teleflex Products Ltd. (Aircraft Division) Basildon.

Sqn. Ldr. M. Greenwood (*Associate*) formerly Group Engineer Officer, Headquarters No. 63 Group, R.A.F. Hawarden, Nr. Chester, is now Senior Engineer Officer at No. 131 M.U., R.A.F. Khormaksar.

R. Hadekel (*Associate Fellow*) formerly Engineering Manager, Sperry Gyroscope Co. Ltd., is now Chief Engineer with Trico-Folberth Ltd.

D. W. Holder (*Fellow*), Head of the High-Speed Laboratory and Deputy Chief Scientific Officer at the N.P.L., Teddington, has been appointed Professor and Head of the Department of Engineering Science, Engineering Laboratory, Parks Road, Oxford.

Wing Cdr. D. K. Kempston (*Associate Fellow*) formerly of the Directorate of Aircraft Engineering, Air Ministry, is now C.O., No. 71 M.U., R.A.F., Bicester.

S. V. Molony (*Graduate*) formerly Results Engineer, Government Aircraft Factory, Fishermen's Bend, Melbourne, is now Stress Engineer, Structural Department, de Havilland Aircraft Co. Ltd., Hatfield.

Dr. T. R. F. Nonweiler (*Associate Fellow*), of Queen's University, Belfast, has been appointed to the Mechan Chair of Aeronautics and Fluid Mechanics, Glasgow.

J. M. Nicholson (*Associate*) formerly with de Havilland Company is now Manager, Flight Operations, Beagle Group, British Executive and General Aviation.

Air Cdre. V. C. Otter (*Associate Fellow*), formerly in Command of No. 32 Maintenance Unit, St. Athan, is now S.T.S.O., Flying Training Command, Shinfield Park.

Wing Commander L. C. N. Penney (*Associate Fellow*) has retired from the R.A.F. and is now with the Directorate of Engine Research & Development, Ministry of Aviation.

F. E. G. Quinn (*Associate*), formerly Aviation Sales Representative and Technical Consultant in Africa for Vacuum Oil Co. Ltd. and a member of Council of the Southern Africa Division of the Society, has been posted to London as Assistant Aviation Sales Representative for Europe with Mobil Oil International Ltd.

D. R. Rees (*Graduate*) formerly Section Leader (Helicopters) Aero Office, Fairey Aviation Co. Ltd., Hayes, is now Project Engineer, Hawker Aircraft Limited, Kingston-upon-Thames.

Capt. R. J. Ritchie (*Associate*) formerly a Qantas captain, has been appointed the Deputy Chief Executive and Deputy General Manager of Qantas Empire Airways.

S. K. Sahiar (*Associate Fellow*) formerly Technical Engineer, Bristol Aircraft Ltd. (Weston Division), is now Senior Scientific Officer, Grade 1, Ministry of Defence, R. & D. Organisation, Government of India, India.

Flt. Lt. D. R. Shallow (*Associate*) formerly R.A.F., Germany, is now at H.Q. Maintenance Command.

D. S. Snow (*Associate Fellow*) formerly Senior Stressman, de Havilland Aircraft Co. Ltd., Hatfield, is now Senior Stressman, Hunting Aircraft Ltd., Luton Airport.

Wing Cdr. J. P. Spillane (*Associate Fellow*) formerly Command Missile Engineer Officer, H.Q. Bomber Command, is now R.A.F. Liaison Officer in the Ballistic Missile Division at Norton A.F.B. California.

C. P. Stocks (*Graduate*) formerly with Sir W. G. Armstrong Whitworth Aircraft Ltd., Coventry, is now an

Aerodynamicist with British Executive and General Aviation Ltd., Shoreham.

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R. B. STRATTON (*Associate Fellow*) formerly Chief Development Engineer, Helicopter Division, Saunders-Roe Ltd., is now with British Executive and General Aviation Ltd., Shoreham Airport.

B. R. TEREE (*Associate Fellow*) formerly Vice-President Engineering, Republic Manufacturing Co., Cleveland, is now Manager, Market Development, Weston Hydraulics Limited, Van Nuys, California.

A. TOMLINSON (*Associate Fellow*) formerly Computer Programmer, English Electric Aviation Ltd., Warton, is now Computer Programming Instructor, English Electric Co. Ltd., Data Processing Division, Stoke-on-Trent.

C. TORKINGTON (*Graduate*) formerly Stress Engineer, Vickers-Armstrongs (Aircraft) Ltd., Weybridge, is now Experimental Officer, Grade 3, Aeronautical Research Laboratories, Fishermen's Bend, Melbourne.

R. UTTING (*Associate Fellow*) formerly with Dowty Rotol Ltd., is now Technical Engineer with Bristol Aircraft Ltd., Filton, Bristol.

J. C. WALLIN (*Associate Fellow*) formerly Senior Designer, is now Chief Power Plant Engineer, Vickers-Armstrongs (Aircraft) Ltd.

Lt. Cdr. E. W. WHITLEY, R.N. (*Associate*) formerly Air Officer, H.M.S. *Murray*, is now at the Admiralty (D.G.A.), Rex House, S.W.1.

S. H. WHITWORTH (*Associate*) formerly Senior Instructor (Airframes and Powerplant) with Royal Netherlands Aircraft Factories "Fokker", is now Assistant Superintendent, Aircraft Division, Field Aircraft Services Ltd., Wymeswold Aerodrome.

P. W. WILKINSON (*Associate*) formerly Flight Technician, D. Napier and Son Ltd., Luton, is now with Aviation Development Inc., St. Gallen, Switzerland.

D. J. WOOLLEY (*Graduate*) formerly Structural Test Engineer, de Havilland Aircraft Co. Ltd., has been appointed Lecturer in Mechanical Engineering at the Barnsley College of Technology.

D. L. WOOD (*Associate Fellow*) has retired from the R.A.F. and has taken up an appointment with the Department of Supply, W.R.E., Salisbury, S. Australia.

K. E. YATES (*Associate Fellow*) formerly Design Engineer, PAC Aero, Santa Monica, is now Design Engineer with Boeing Airplane Co., Washington.

IFAC CONGRESS 1963

The Second Congress of the International Federation of Automatic Control (IFAC) will be held in Basle, Switzerland, in September 1963, at the invitation of the Swiss Association for Automatic Control. The newly-formed Foreign Relations Panel of the British Conference on Automation and Computation will co-ordinate the submission of papers from the U.K. to the congress. Most papers will deal with the theory or application of automatic control; a number will deal with the components of control devices. Subjects to be covered are: *Theory*: discrete systems; stochastic systems; optimal systems; learning systems; systems relability. *Applications*: process dynamics; computer studies of applications, on or off line; optimising or adaptive control applications. *Components*: new and effective devices; measurement of the reliability of components. The final version of any paper by a U.K. author should be in the hands of the BCAC committee not later than 1st June 1962. Offers of papers from the U.K. should be made to the Honorary Secretary, BCAC, c/o The Institution of Electrical Engineers, Savoy Place, W.C.2. General enquiries concerning the congress arrangements should be made to the Secretary of IFAC, Dr.-Ing. G. Ruppel, Prinz-Georg-Strasse, 79, Dusseldorf.

Lecture Summaries

49th Wilbur Wright Memorial Lecture

RESEARCHES IN SPACEFLIGHT TECHNOLOGY
Dr. ABE SILVERSTEIN

To be given on 12th September 1961 at 7 p.m.

Despite the remarkable successes already achieved in space flight, much of the science and technology of this new art is primitive. In the same way the Wright Brothers flew successfully before the aeronautical sciences were developed. Fortunately the research methods and results established in over 50 years of manned flight provide a foundation for rapidly building the new technology.

Manned space flight with its exacting need for performance and safety places the most demanding requirements on the new technology. In the lecture some current researches to extend our understanding of the aerodynamic, propulsion, structural, material, and environmental problems of advanced manned missions will be reviewed and discussed.

Astronautics and Guided Flight Section

PACKAGED LIQUID ROCKET PROPULSION SYSTEMS
W. N. NEAT and K. G. PAGE

To be given on 16th October 1961

In this lecture, the Packaged Liquid Propellant Rocket Engine is defined as a completely self-contained propulsive unit charged with propellant at the factory and thereafter completely sealed. The concept takes the idea of storable propellants a stage further since the sealed units can be transported, handled and stored in their fully charged condition, and are therefore always at instant readiness.

Furthermore, the pre-packaged units contain their own means for pressurisation and ignition and therefore require little or no preparation before use.

The general principles of the operation are described together with some of the design difficulties which have to be overcome. Reference is made to experience in the United States where units of this type have been selected for certain missile applications. The types of missile to which such motors can be beneficially fitted are discussed, together with their application for certain missions in space.

The particular advantages of the pre-packaged units are enumerated. Briefly they appear to be:—

(*a*) Simplicity and reliability. (*b*) Instant readiness. (*c*) Robustness. (*d*) Insensitivity to environmental conditions during storage and firing. (*e*) Flexibility with regard to thrust level and control. (*f*) Performance potential.

Whilst it cannot be claimed that the pre-packaged liquid propellant unit will displace the solid propellant and conventional liquid propellant motors from their established roles, it is suggested that the characteristics of the pre-packaged motor make it especially suitable for certain applications where particular requirements have to be met.

AEROSPACE ENGINEERING INDEX 1959 AND 1960 EDITIONS

Information has been received that publication of the 1959 and 1960 editions of the "Aerospace Engineering Index" has been further delayed because of the change-over to new procedures and format for the 1961 index to "International Aerospace Abstracts." Purchasers will be notified as soon as a firm schedule has been set for the 1959 and 1960 indexes. The Institute of the Aerospace Sciences regrets the inconvenience caused by this delay.

CHANGES OF ADDRESS OR APPOINTMENT

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address. He would also like to know of any change of appointment.

When notifying changes please give the following particulars:—

Name (in block letters) Grade of Membership
New Address (in block letters) Old Address

New appointment—Please give name and address of new employer and position held, and the same information for the previous position held.

Changes of address must be received *before the 15th of the month* in order to be effective for the following month's JOURNAL.

The Journal of the Royal Aeronautical Society

INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

VOLUME 65 SEPTEMBER 1961 NUMBER 609

Nuclear Power in Flight

BY

A. D. BAXTER, M.Eng., F.R.Ae.S., M.I. Mech.E.

(*Executive Director (Engineering), The de Havilland Engine Co. Ltd.*)

The 1,190th lecture to be given before the Society—and the 44th Main Lecture to be held at a Branch centre—" Nuclear Power in Flight", by Professor A. D. Baxter, M.Eng., F.R.Ae.S., M.I.Mech.E., at that time Director and Chief Executive, Rockets and Nuclear Power, and now Executive Director (Engineering), The de Havilland Engine Co. Ltd., was given under the auspices of the Swindon Branch of the Society on 2nd February 1961. Mr. S. R. Hughes, A.F.R.Ae.S., A.F.I.A.S., Chairman of the Swindon Branch, opened the meeting by welcoming the President of the Society, Dr. E. S. Moult, C.B.E., B.Sc.Eng., F.R.Ae.S., M.I.Mech.E., and other distinguished guests attending this first Main Society Lecture to be given at Swindon. Dr. Moult, who presided for the rest of the meeting, expressed his great pleasure at being present on this occasion. Introducing the lecturer, the President said that Profesor Baxter, as he was still known, was educated at Liverpool University and from 1930-34 served an apprenticeship with the Daimler Company. During this time he took his pilot's "A" licence and was commissioned in the R.A.F.O. After a year as Research Engineer with the Institution of Automobile Engineers, he joined the Royal Aircraft Establishment in 1935 as a Technical Engineer working on gas turbine research and later, rocket propulsion. From 1947 to 1950 he was Superintendent, Rocket Propulsion Dept., R.A.E., and then joined the new College of Aeronautics as Professor of Aircraft Propulsion, becoming Deputy Principal of the College also, in 1954. In 1957 Professor Baxter left the College of Aeronautics to join The de Havilland Engine Co. Ltd. as Chief Executive, Rocket Engine Division.

1. Introduction

The technology associated with flight has advanced at an almost exponential rate during the past two decades. Much of this can be ascribed to the introduction and development of the gas turbine power plant and jet propulsion. Almost parallel with this, atomic energy became a reality and its unique feature of negligible fuel consumption naturally focused attention upon its possibilities for flight. In the first instance the spotlight was upon aircraft flight, but the advent of space flight has added rocket propulsion and auxiliary power in space to the uses which have been receiving attention.

Although the first attraction of almost limitless endurance was quickly clouded by the enormous weight of power plant required, this has not deterred the Americans and Russians from making practical studies and there is no doubt that interest continues. In view of the weight handicap, many aircraft applications are ruled out, but some possibilities still remain. These include long endurance, long range, and high speed. Civil aircraft might well take advantage of the latter qualities and they all have obvious military value.

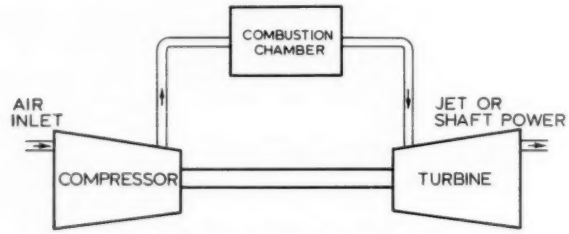
Up to the present time only one paper[1] has been presented to the Society on the subject and it took a rather pessimistic view of the prospects. It admitted that nuclear powered flight was technically feasible, but thought it would be hopelessly uneconomic, bristling with problems and so distant as to be barely worth considering. This view has been held in the early days of almost every new engineering development and should not, therefore, be accepted without reservations. It is true that so far little factual information on progress towards successful flight has been released, but this does not imply that it is necessarily remote. It does, however, mean that the remainder of this paper must, of necessity, be mainly of a theoretical or conjectural nature. It will examine some of the alternatives that are now emerging as possible engine systems, and indicate some approximate power plant sizes and layouts with their problems. Previous discussions of these are included in the useful list of papers given in Ref. 1 and the selection of later literature presented at the end of this paper.

2. Engine Cycles

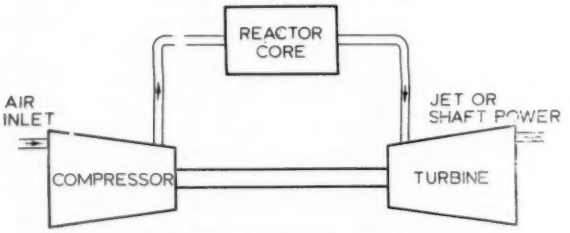
In all engines there is an input of energy which is converted to an output of work. In aero engines the initial energy is supplied as a chemical fuel which is converted to heat energy in a combustion chamber and thence to shaft or jet power. The use of nuclear fuel only modifies this in that its energy is converted to heat in a reactor and this must act as an alternative to the combustion chamber, as shown diagrammatically in Fig. 1 for a gas turbine engine. Similar arrangements would apply, in principle, to both ramjets and rockets although the practical layouts could differ widely.

2.1. NUCLEAR CONSIDERATIONS

The introduction of a reactor as a heat source involves the transfer of heat from its point of generation to the engine working fluid and there are a number of ways of doing this. In conventional reactors the heat is removed by circulating either a liquid or a gas over the fuel elements and then through a heat exchanger. Liquids are, at first sight, more attractive because their greater density and better thermal conductivity permit smaller flow passages and more compact design. Water



(*a*) Chemical fuel gas turbine.



(*b*) Open cycle nuclear gas turbine.

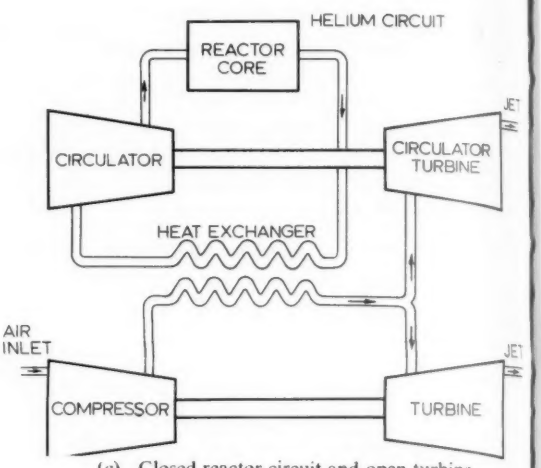
FIGURE 1. Chemical and nuclear energy alternatives for gas turbines.

is one such liquid but because it boils at relatively low temperatures even under pressure (*e.g.* 285°C. at 1,000 lb./in.^{2}), it is no use in gas turbines where temperatures must be very much higher for efficient operation. Liquid salts and metals have also been used and are much better in this respect. Mixtures of sodium and potassium, for instance, have a liquid temperature range from slightly above atmospheric to about 825°C. Lithium and bismuth are other possibilities and some relevant physical properties are compared in Table I. Unfortunately each has some drawbacks, such as the high inflammability risk of sodium in air, the cost of bismuth, the corrosiveness of lithium and its adverse nuclear properties.

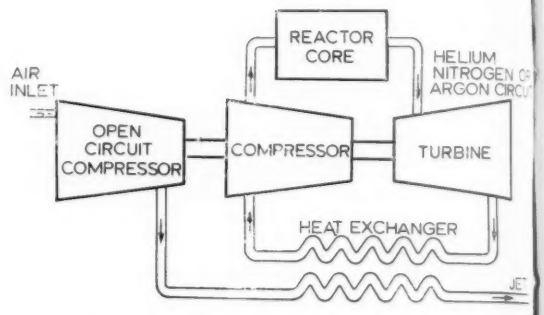
TABLE I

COMPARISON OF REACTOR COOLANTS

Coolant	*Liquid Metals*				
	Sodium	*Potassium*	*70/30 Sodium/ Potassium*	*Lithium*	*Bismuth*
Melting Pt. °C	98	64	40	186	271
Boiling Pt. °C	883	760	825	1,317	1,477
Density lb/cu.ft.	57·9	51·5	55·9	31·7	6,260
Specific Heat CHU/lb. °C	0·305	0·182	0·210	1·06	0·036
Rel. Pumping Power	0·35	2·41	1·0	0·05	2·70
Coolant	*Gases*				
	Helium	*Nitrogen*	*Carbon dioxide*	*Argon*	*Hydrogen*
Density lb/cu.ft.	0·011	0·078	0·123	0·111	0·006
Specific Heat CHU/lb. °C	1·25	0·243	0·202	0·123	3·40
Rel. Pumping Power	170	360	122	1,730	30
Rel. Circulator vol.	20·0	4·6	1·0	19·2	6·0



(*a*) Closed reactor circuit and open turbine.



(*b*) Closed reactor circuit and closed turbine.

FIGURE 2. Alternative closed cycle nuclear gas turbine systems.

On the other hand, the use of gas avoids any temperature limitation due to change of state, but poorer physical characteristics involve larger heat transfer surfaces, greater temperature and pressure differentials and more severe leakage problems. In this country experience has been mainly with gas cooled reactors and steady progress is being made towards higher operating temperatures, as shown in Table II. The ultimate

TABLE II

BRITISH GAS COOLED REACTOR PROGRESS

Experimental Reactors			
Name	*Year*	*Thermal Power* MW.	*Gas Temperature* °C
Calder Hall	1956	200	333
A.G.R., Windscale	1961	100	575
H.T.G.C.R., Winfrith	1963	20	750
Power Generation Reactors (C.E.G.B.)			
Chapel Cross	1958	200	333
Bradwell	1961	531	390
Hunterston	1962	569	400
Dungeness	1964	835	410

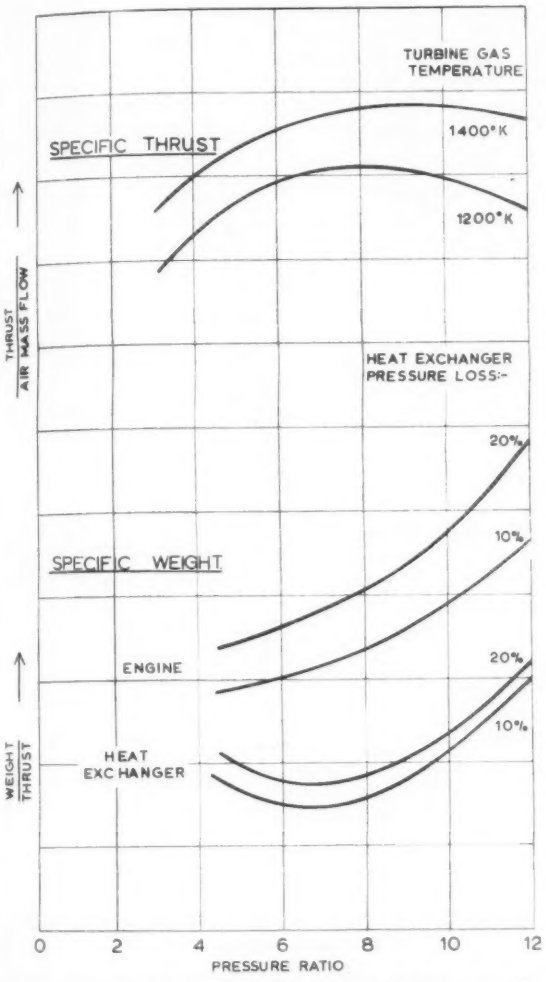


FIGURE 3. Thrust and weight optimisation with pressure ratio for closed cycle turbojet.

limitation will be the strength of the structural materials under temperature conditions. The gases used are normally inert and unaffected by radio-activity. Carbon dioxide, argon and helium are typical examples compared in Table I.

By contrast gas turbines operate with atmospheric air as their working fluid and the use of other gases or liquids will involve some form of closed circuit for the reactor. Two alternatives are shown in Fig. 2, (*a*) and (*b*). These can be compared with the open cycle layout of Fig. 1 (*b*) in which air is heated directly in the reactor. Both open and closed cycles have advantages and work in the U.S.A. is proceeding with both.

The former is less complicated, but under high altitude conditions the air density is low and sufficient heat cannot be removed from the reactor core unless the cooling passages are large. This results in a large overall reactor and a large shielding weight which may be critical. The indirect system permits a compact reactor because the cooling gas is always at high density, but it requires a circulator for the gas and a heat exchanger.

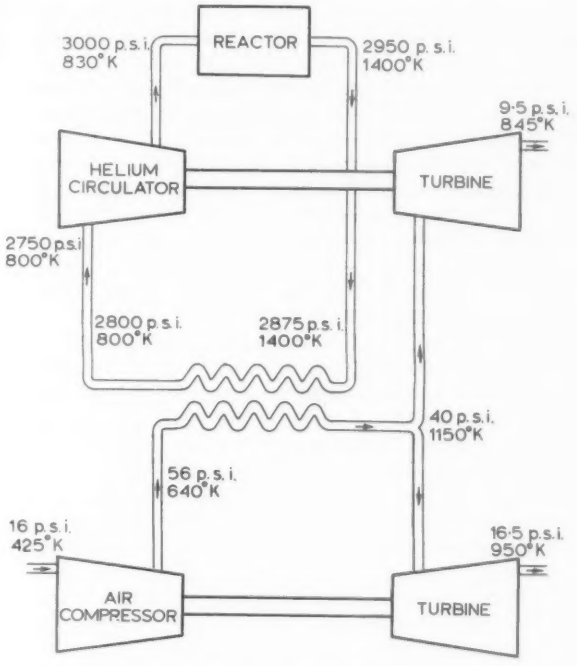


FIGURE 4. Typical pressures and temperatures in a closed cycle turbojet.

In Fig. 2 (*a*) it is arranged so that the engine still uses atmospheric air as its working fluid, but engine maximum temperature is inevitably lower than in the open cycle. This drawback can be avoided, as in Fig. 2 (*b*), by a closed cycle incorporating the turbine. This has the advantage of transferring the heat exchanger to the lowest temperature and pressure side of the system, but it is difficult to remove the exhaust heat at high altitude without excessive bulk. Too high a gas temperature on return to the compressor would reduce the efficiency and output severely. Furthermore the use of helium to assist heat transfer in the primary circuit might be unacceptable because of the large number of compressor stages this gas requires for a large pressure ratio.

2.2. THERMODYNAMIC CYCLES

Generally it may be assumed that turbojet engines will be needed to meet any modern aircraft speed requirements so that the thermodynamic considerations must be based on this. They must also take into account the need for optimising the power plant weight. Thus, it does not follow that minimum pressure drop between compressor and turbine is essential or that the pressure ratio should be the conventional optimum.

2.3. CLOSED CYCLE ENGINE

The foregoing considerations are illustrated in Fig. 3 in generalised form for the high temperature heat exchanger type of plant. Engine weight falls steadily with reducing pressure ratio and pressure loss, but heat exchanger weight has a minimum with both. Equally, specific thrust has an optimum with pressure ratio, but increases with increasing maximum cycle

temperature. The combination of these and other factors will determine minimum overall plant specific weight.

Practically, the turbine temperature will be restricted by the permissible limits on temperature of the nuclear fuel elements and their supports, or of the heat exchanger tubes. An ambitious, but not impossible value for the cooling gas temperature after passing through the reactor might be 1,400°K. and a suitable heat exchanger could then raise the turbine air to about 1,200°K. Such a temperature is not excessive and modern cooling techniques would permit higher values if the other limitations did not restrict it.

Some typical figures of temperature and pressure at various points in an engine are given in Fig. 4. The high pressure of the reactor cooling gas is noteworthy and also its substantial pressure drop. This, again, is a compromise between bulk and weight of reactor, ducting and heat exchanger, and the circulating power. By using helium at some seventy times normal density in this circuit the heat transfer rates are greatly increased and the flow passages reduced. The power required to pump the gas around the circuit is approximately 70 h.p. per MW of the heat transported, that is, about five per cent of the reactor output. On the gas turbine side of the unit, the air temperatures and pressures are normal except for the relatively large pressure drop between compressor and turbine.

2.4. OPEN CYCLE ENGINE

Similar optimisation considerations apply to the open cycle engine. These lead to results of the form shown in Fig. 5 which relates the overall power plant specific weight to pressure ratio. Two cases have been examined, the first corresponding to the closed cycle discussed above where the assumed design condition was for a supersonic aircraft flying at 50,000 ft., and the second to compare this with a subsonic aircraft at 36,000 ft. In both cases there is a marked reduction in weight with increasing gas temperature. With the open cycle, such an increase is possible because of the absence of a heat exchanger. In fact the gas temperature will be that of the cooling gas in the reactor and this was taken as 1,400°K. for the closed cycle. At this temperature the optimum pressure ratio is nearly double that at 1,200°K., and even this is still much lower than in the subsonic case. The latter is well outside conventional engine practice and might involve a great deal of new design and development. Also from Fig. 5 it will be noticed that a relatively large pressure drop in the reactor cooling system is justified, as in the closed cycle.

3. Power Plant Components

Before considering the complete power plant further it may be worth examining some of the major components and their influence on the overall assembly. They are not all required in all engine arrangements and the following paragraphs refer particularly to the closed cycle reactor with open cycle turbine (Fig. 2 (*a*)) except where specially noted.

3.1. REACTOR

At flight speeds of $M=2{\cdot}2$, the conventional turbo-

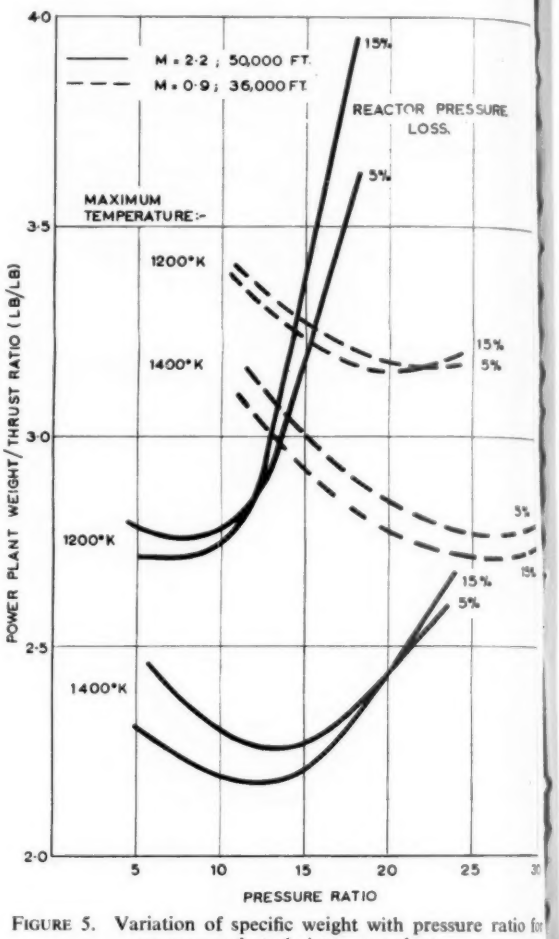


FIGURE 5. Variation of specific weight with pressure ratio for an open cycle turbojet power plant.

jet has an overall efficiency of nearly 40 per cent, but the nuclear turbojet efficiency will be only 30 per cent, due to the high internal pressure losses. This is not of prime importance from the fuel consumption point of view, but it does increase the heat output and transfer problems of the reactor. For example, a thrust of 50,000 lb. requires 490 MW of heat instead of 360 MW. In this country Calder Hall produces 200 MW of heat per reactor and the first Central Electricity Generating Board station, Bradwell, to be completed in 1961, will provide 530 MW (Table II).

These stations operate with thermal reactors, that is, reactors which employ a large proportion of moderating material to slow down the free neutrons to thermal velocities and a relatively small proportion of fissile U^{235}. The cores of such reactors are large, but could be reduced by greater enrichment with U^{235}, and a proportionate reduction in moderator. Ultimately, very little moderator would be used and the neutrons would move much faster. This gives the so-called "fast" reactor. An illustration of the effect of these changes in moderator/uranium ratio on the weight of the uranium required and the core volume for a beryllia moderator is given in Fig. 6. Beryllia is the moderator suggested

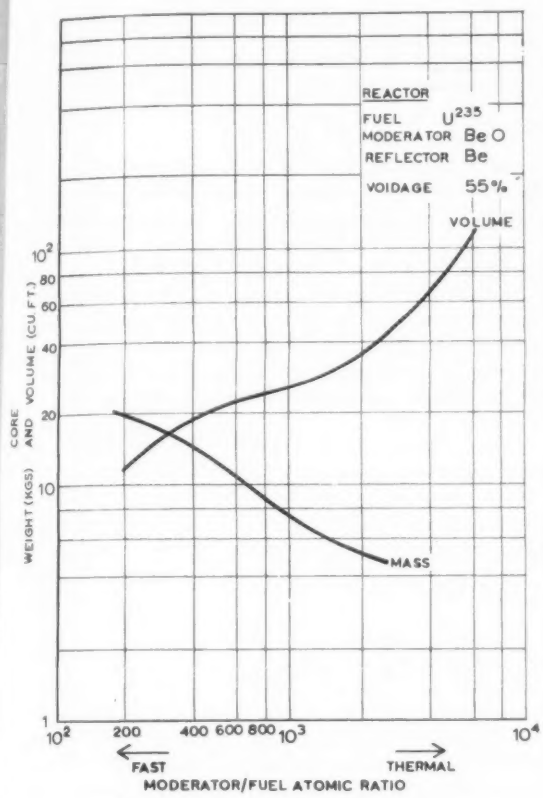


FIGURE 6. Reactor core parameters.

because of its excellent nuclear and high temperature properties. Graphite is an alternative but has poor compatibility with air at high temperature and there are others, but each has some disadvantage.

One of the major problems is to include sufficient voidage to permit adequate gas flow through the core to transport the heat away. Another is to provide the surface area necessary to transfer it from the core to the gas. Conventional designs give thermal outputs of less than 1 MW per cu. ft. of core, but outputs of 30 MW per cu. ft. have been suggested[1] and 50 MW per cu. ft. or more does not seem out of the question with some ingenuity in design. Thus outputs of 500 MW could be obtained from a core of say 2½ ft. diameter by 2½ ft. long, at a rating of 40 MW per cu. ft. From Fig. 6 this would require an investment of 20 kg. of U^{235} and the moderator/fuel ratio would be about 200: 1.

Normally the fuel elements are in the form of long rods sealed in metal "cans." For the large output, high temperature, and high heat transfer rate required, such a system is inadequate. One alternative might be to form the core of a very large number of small spheres of beryllia with the fissile material sealed inside. The beryllia acts both as moderator and "can", gives a much more robust arrangement within the volume limitations and has other advantages referred to later.

The total weight of the core will be of the order of 1,000 lb., but this is surrounded by a beryllium neutron reflector which adds almost 3,000 lb. Although not strictly necessary, this is justified by economies in fuel investment and shield weight. Outside it, there is a pressure vessel and the radiation shielding.

For an open cycle engine, instead of helium at 3,000 lb./in.² removing heat from the core, there is air at about 100 lb./in.² and hence the transfer surface must be greater. Thus the core will be larger, possibly 3 ft. diameter by 5 ft. long, and correspondingly heavier.

3.2. SHIELDING

Shielding is necessary to protect air and ground crew, passengers and others in close proximity to the reactor, as well as aircraft structure and equipment, from harmful radiations. These are primarily fast neutrons and gamma rays. The former are slowed down by collision with the nuclei of light atoms, such as hydrogen or carbon, and the latter are attenuated by interaction with electrons. This implies that dense materials, in which electrons are crowded together, are most effective. Thus the shielding needs to be in two parts; the first may be water or hydrocarbon fuel, the second may be lead or steel. Full shielding of even the smallest size core involves a prohibitive weight, but this can be overcome by two techniques—shadow shielding and split shielding.

The first introduces a variable degree of shielding between the reactor and the areas needing protection. Radiation travels in straight lines and hence materials and people within the shadow of the shield will be protected. Unfortunately some scattering of the radiation not attenuated by the shield occurs when it reacts with particles of air or structure and this secondary radiation can be reflected on to vulnerable parts. To

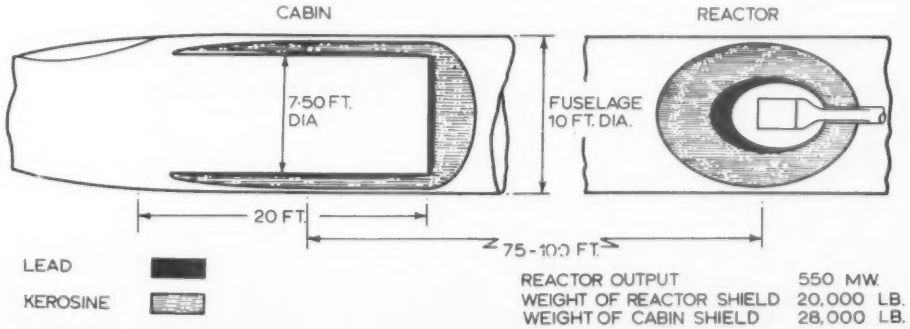


FIGURE 7. Layout of cabin and reactor shielding.

overcome this some shielding may be placed around the area to be protected. It is found that this leads to an optimum division of shielding between the cabin and reactor for minimum total weight.

The general layout of the shielding is shown in Fig. 7. The reactor has a fairly heavy lead shield (about one ft. thick) towards the cabin and a reducing amount in other directions. The lead is surrounded by kerosine varying from a maximum thickness of 4 ft. facing forward to 2 ft. facing rearward. The cabin, when situated some 75 ft. from the reactor, will require relatively less shielding. The weight will vary, of course, with cabin size. If, instead of $7\frac{1}{2}$ ft. diameter by 20 ft. long, it were reduced to 6 ft. diameter by 12 ft., the shield could be reduced by some 5,000 lb. Against this, the larger core necessary with the open cycle engine will involve more shielding.

3.3. HEAT EXCHANGERS

The transfer of reactor heat in closed cycle engines from the primary gas to the working gas is one of the major engine design problems. There are no difficulties about calculating the necessary heat exchanger areas, temperature drops and passage sizes, but there are many unknowns in selection of materials, fabrication and assembly.

The hot gas is at 1,400°K. and must raise the air to 1,200°K. It is at a pressure of 3,000 lb./in.^{2} and must not over-stress the tubes. These must have a reasonable life and be assembled between the engine compressor and turbine with the minimum of bulk and weight. The volume of the heat exchanger is approximately proportional to the diameter of its tubes and, to restrict it to an overall diameter comparable with that of the engine, it requires tubes about $\frac{1}{16}$ inch bore by 0·010 in. thick. These will be stressed to 4 tons/in.^{2} and there are very few materials capable of working at this stress and temperature for any length of time. Suitably alloyed molybdenum or niobium might be satisfactory, but both would need protection on the outside from oxidisation. New techniques for assembling the large number of fine tubes into header plates and welding to form reliable leak-tight joints would also be essential.

Some idea of the problem can be gained from the fact that to transfer 100 MW heat requires 60 miles of tube which is confined within a total volume of 185 cu. ft. and a weight of 5,000 lb. Neither the weight nor the problem exist for the open cycle engine.

3.4. CIRCULATORS

Gas circulators are required to pump helium round the primary circuit. These are conventional compressors of low pressure ratio (about 1·10: 1), but need a number of stages (about 6) for even this low value. They can be driven by turbines accepting some of the main air supply bled from the propulsive engines. The main difficulty of this arrangement is to prevent helium leakage between the rotating drive shaft and the compressor casing. Various forms of gland have been devised, but a much higher sealing standard is required than on any conventional system.

The problem could be overcome by using a self-driving turbo-circulator which was contained completely within the primary circuit. Unfortunately this would involve a much larger compressor in order to provide the extra pressure ratio to drive the turbine. Instead of 6 stages, 32 might be required. Furthermore, the temperature drop through the turbine would be almost 150°C. and, as a result, the temperature available at the heat exchanger would be low. As with heat exchangers, there is no problem with the open cycle engine.

3.5. TURBOJETS

The main propulsion engines are basically the same as any conventional turbojets suitable for the same performance, except for the higher pressure drop between compressor and turbine and the air bleed to the circulator turbine. The layout is shown in Fig. 8 with the heat exchanger disposed circumferentially in the place of the normal combustion chamber. Actually a combustion chamber will probably be incorporated in addition so that, with the reactor inoperative, thrust is still available. The combustion system could also be used to boost the maximum air temperature leaving the heat exchanger to the maximum that the turbine can stand.

This arrangement increases the overall length of the engine and might introduce shaft whirling problems.

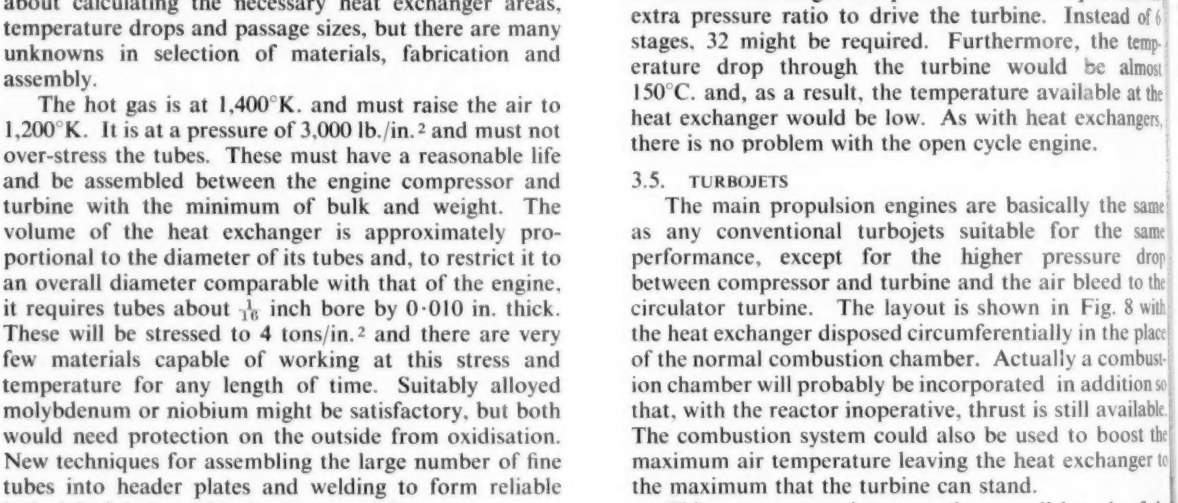


FIGURE 8. Layout of nuclear-powered turbojet.

TABLE III
SUPERSONIC AIRCRAFT WEIGHT ANALYSIS

Component	*Conventional*	*Nuclear*
Structure + Services	29%	32·5%
Power Plant	12%	57·5%
Fuel	54%	—
Payload	5%	10%

but it is preferable to reducing length at the expense of diameter. Some calculations based on scaling the de Havilland Gyron engine indicate that an engine with an overall length of 168 in. and an overall diameter of 56½ in. could produce a sea level static thrust of 26,000 lb. for an all-up weight, including heat exchanger, of 10,250 lb.

The open cycle engine is lighter and, because it can take full advantage of the reactor temperature, it has a better specific thrust.

4. Overall Power Plant

It has been emphasised that power plant weight is a critical factor in achieving a practical aircraft, but no indication has yet been given of what overall weight might be possible nor of its influence on aircraft size and power requirement.

An approximate breakdown of weight for a supersonic aircraft[2] is given in Table III together with the re-arrangement that would be necessary for a nuclear power plant. The structure would be slightly heavier for the latter, but the power plant weight should be less than the equivalent of the original engine plus its fuel. This would allow 10 per cent to be disposable as payload and chemical fuel, and leave 57·5 per cent of the all-up weight for reactor, shielding, heat exchanger, ducting and engines. Some indication of the relative weights of such components has been given in the previous section, but the combined result is presented in Fig. 9 which shows their variation in weight with thrust for a closed cycle plant designed for operation at $M = 2 \cdot 2$ at 50,000 ft.

If the lift/drag ratio for a supersonic aircraft is assumed to be 6: 1, then it follows from Table III that the nuclear power plant weight/thrust ratio must not exceed 3·45: 1. From Fig. 5 it can be seen that this is easily obtainable, but it is so only with a sufficiently high thrust level because there is considerable power plant weight which is independent of thrust. This is clear from Fig. 9, where weight/thrust ratio is plotted in addition to absolute weights. The limiting value occurs at nearly 50,000 lb. thrust and this means a minimum aircraft weight of 300,000 lb.

Some comparative figures for open and closed cycle engines in an aircraft slightly larger than this are given in Table IV.

The open cycle plant is apparently lighter, especially if allowance is made for the higher gas temperature which is possible. It is only true, however, if the ducts leading air to and from the reactor are very short. This restricts the installation severely and if an equivalent short duct closed cycle installation is accepted, its weight might be only 135,000 lb. Conversely, a long duct open cycle installation might, if it were not entirely impracticable, weigh much more than the closed cycle plant. For a

TABLE IV
POWER PLANT PERFORMANCE

Design Condition	*Closed Cycle*	*Open Cycle*		
		$M = 2 \cdot 2$ Alt. = 50,000 ft.		$M = 0 \cdot 9$ Alt. = 36,000 ft.
Thrust lb.	55,000	55,000	55,000	25,000
Engine Temperature °K	1,200	1,200	1,400	1,400
Engine Pressure Ratio	6: 1	6: 1	12: 1	25: 1
Power Plant Weight lb.	172,000	148,000	120,000	68,000

subsonic aircraft much less thrust is necessary and there is a consequent decrease in power plant weight, as shown in the last column of Table IV. Some of this is because fewer engines are necessary but a considerable proportion results from the smaller reactor resulting from the reduced thermal output.

The reactor size will limit the thrust if it is too small

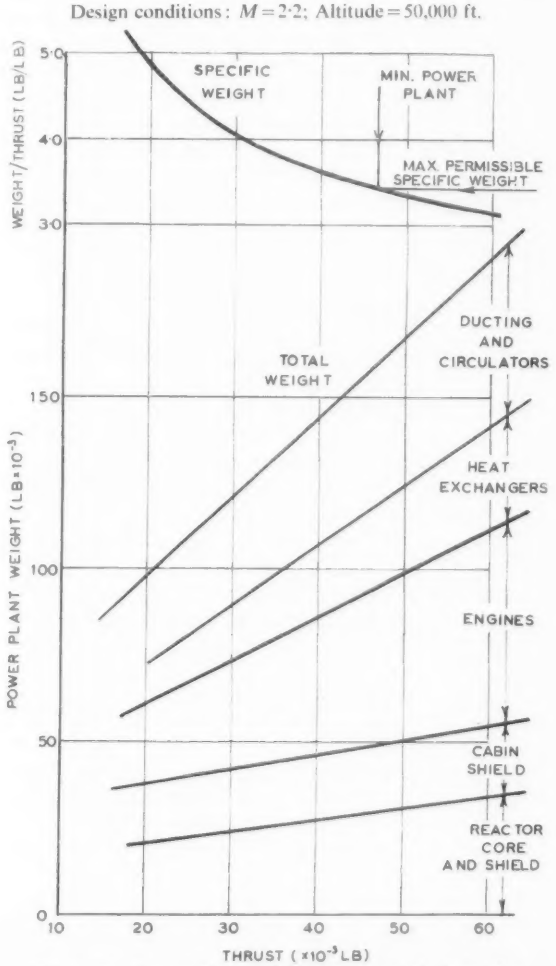


FIGURE 9. Approximate weight variation with thrust for supersonic closed cycle turbojet.

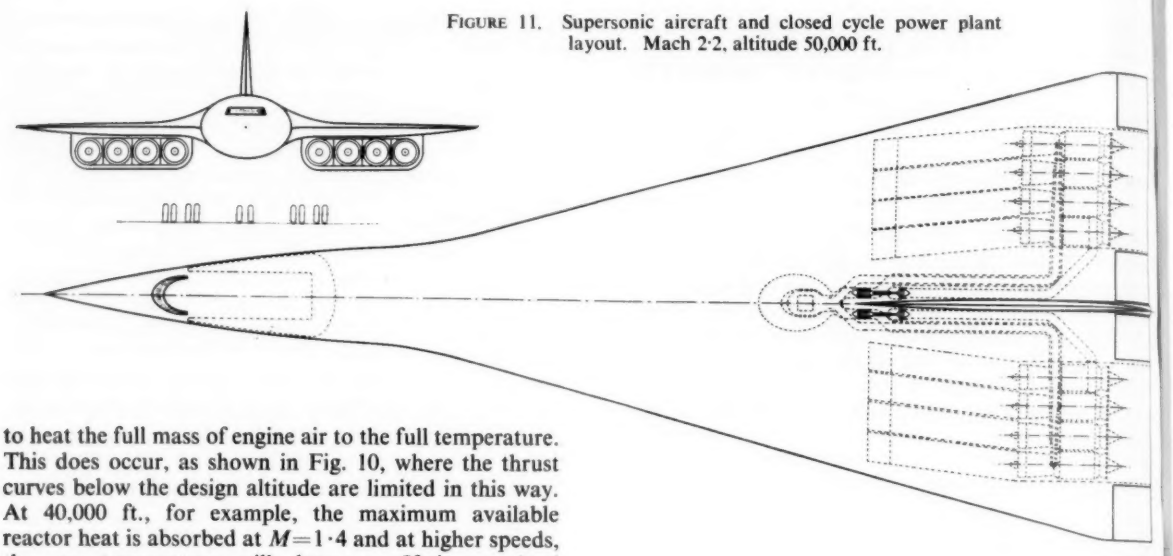


FIGURE 11. Supersonic aircraft and closed cycle power plant layout. Mach 2·2, altitude 50,000 ft.

to heat the full mass of engine air to the full temperature. This does occur, as shown in Fig. 10, where the thrust curves below the design altitude are limited in this way. At 40,000 ft., for example, the maximum available reactor heat is absorbed at $M=1\cdot4$ and at higher speeds, the gas temperature will decrease. If it remained constant, the thrust would increase as indicated by the broken line. This limitation becomes even more marked at lower altitudes and at sea level static conditions the thrust available is only 50 per cent of the potential.

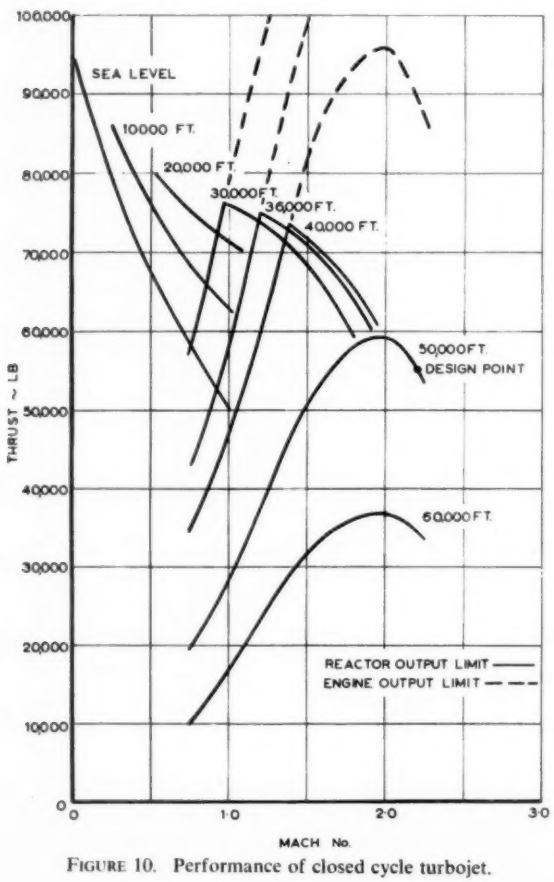


FIGURE 10. Performance of closed cycle turbojet.

This could be recovered, if required, by the use of chemical fuel to boost the gas temperature.

5. Aircraft Installation and Operation

While the problems of the power plant itself are of prime importance, there remain a number associated with the aircraft which are peculiar to the nuclear system. Apart from installation, there are among others, operational, safety, maintenance and economic considerations.

5.1. INSTALLATION

Installation is especially difficult because more than 50 per cent of the all-up weight will be concentrated in two small areas—the cabin and the rear fuselage. Because the reactor represents a major portion of the weight, it will be located close to the centre of gravity, but the cabin should be as far away from the reactor as possible. As a consequence the fuselage structure between them will need special strength to cope with the exceptional bending moments which may be imposed. It will also need to be of adequate cross section to house the shielding and this means about 10 ft. diameter, unless local bulges are introduced or a restricted cabin used.

It is almost inevitable that the aircraft will be of a canard or narrow delta form. In both cases there is a problem of engine installation. Multiple engines will be used both for safety and design convenience, but it is unlikely that more than one reactor can be incorporated. Very long intake and exhaust air pipes may be necessary and the length of the high pressure gas ducting between reactor and engines may introduce a severe weight penalty. It is also necessary to include engine isolating valves and their installation may be both heavy and bulky. Alternative installations are illustrated in Figs. 11 and 12. The former is more attractive for the closed cycle power plant as there is more latitude in the disposal of the engines and their adjustment in relation to the centre of gravity. On the other hand the ventral nacelle

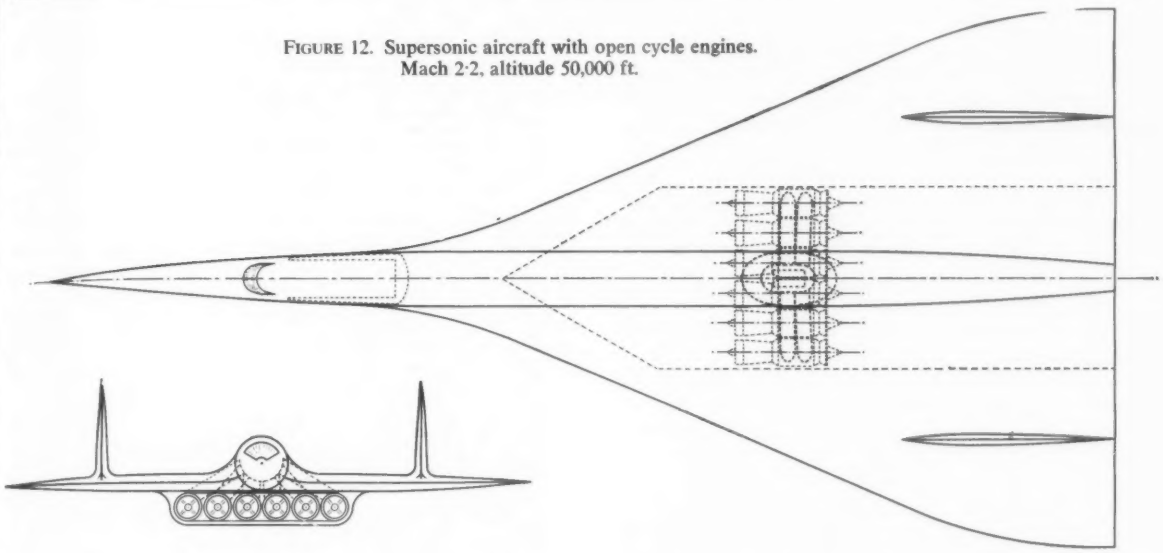


FIGURE 12. Supersonic aircraft with open cycle engines.
Mach 2·2, altitude 50,000 ft.

permits relatively short gas transfer pipes and this is vital for the open cycle engine.

Because of the constant take-off and landing weight, the undercarriage will need to be stronger than normal. On the other hand there will be little shift in c.g. Some correction could be made in flight if necessary by pumping some of the liquid shielding from cabin to reactor or vice versa. Wing structure should be simplified because the large fuel tankage usually required will be omitted. There may be some material problems arising from irradiation effects, but primary structure strength will not be adversely affected during a normal aircraft life. Plastics, insulators, seals, gaskets, oil and similar materials may, however, present problems, not only because of breakdown of their normal properties, but due to becoming radio-active. This could make maintenance and servicing extremely difficult unless special design precautions are taken. One further radiation effect which could be a source of trouble in supersonic flight is shield heating. The radiation energy absorbed by it is converted to heat and at flight speeds above $M=2$ there may be no natural heat sink available.

5.2. OPERATION

The great operational advantage of the nuclear aircraft is its endurance. So far this has been assumed to be infinite but, in fact, there are several limitations. The first is a nuclear one and usually occurs when something like 10 per cent of the uranium fuel has been fissioned. At this stage it is necessary to remove the fuel elements and re-process them to abstract spent material. The fuel is used at almost one lb. for each 450 megawatt days of power. Thus, for a reactor containing 20 kgs. of fissile material, this point is reached in about $3\frac{1}{2}$ days at $M=2{\cdot}2$ or $9\frac{1}{2}$ days at $M=0{\cdot}9$.

From the turbojet point of view this means something between 80 and 240 hours continuous operation; this should be well within its capability, but would call for overhaul after relatively few flights. It should also be remembered that present engines in service normally operate less than ten hours each day and have daily inspections. On the aircraft side a similar state exists and this applies particularly to instruments, radio and other equipment. Serviceability of all these over long continuous periods may require special attention. Finally, there is the human element. It is possible for crews with suitable environments to remain in flight for long periods, but cabin space will be confined and a heavy nervous strain may be imposed.

During endurance flying the aircraft will normally operate with a steady power demand corresponding to designed cruising conditions. This will be met by the full power output of the reactor and only a fine regulation will be required. Coarser control will be needed during starting and stopping, but both objectives could be achieved by a system of adding or removing fuel pebbles in the core. This might be combined with the alternative or additional conventional chemical combustion system to give greater flexibility.

It is likely that, in the interests of safety, take-off and landing will be performed with the reactor shut down and the turbines operating only on chemical fuel. This is particularly important at the end of flight when reactor "poisoning" and shut-down heating effects are present.

The "poisoning" is due to the equilibrium between the formation and breakdown of the fission product, xenon, being disturbed during any change of reactor power. The proportion of xenon, with its affinity for neutrons, increases during reduced reactor output and in thermal reactors may be sufficient to render the core non-critical even with full power control setting. It is a temporary phase and disappears when the xenon equilibrium has been restored. The phenomenon is not serious in fast or intermediate reactors and can be overcome by providing additional reactivity. This is expensive in extra fuel, but might be co-ordinated with the power control system in which the number of fuel pebbles are varied to obtain the desired output. An alternative power control or one used in conjunction with varying the pebbles, would be to move the reflector material so that more or less neutrons were reflected.

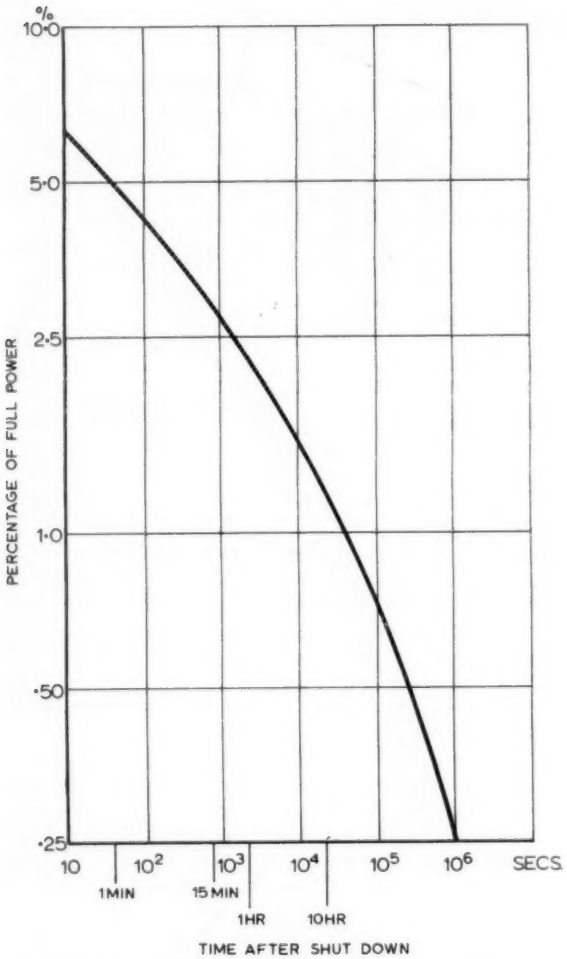


FIGURE 13. Variation of nuclear after-heat with time.

The other feature of the reactor is its "delayed" heat release on shut down. Thus, even several hours afterwards there is appreciable heat generated in the core, as shown in Fig. 13. This would cause melting unless removed by continuing the gas flow. During flight this is possible and the chemical combustion system will supplement the heat so that the output required is obtained. After landing, one or more engines would have to remain at idling speed for some time or some ground-operated system used for removing the heat. It may be noted that, provided the reactor is not to be re-started in flight, some of the kerosine required for shielding can be used in the engines. This is because neutron radiation will have been greatly reduced.

5.3. SAFETY

All the foregoing technical problems are overshadowed by the question of safety. A crash could result in the release of radio-active fission products which would be dangerous, not only in the immediate vicinity, but over a wide area. Two alternatives exist, the first to ensure that operations never bring the aircraft within a populated area and the second, to minimise the consequence of a crash.

The first might be acceptable for military operations and it is possible to conceive of Arctic or Desert bases which could be used in this manner, or the use of flying boats and water bases might be advantageous.

The second will need new design concepts. For example, instead of making an impossible attempt to maintain the reactor integrity in a crash and so contain the radio-activity, the design might be arranged to assist the break-up in a manner that would reduce the release of activity. Thus, if the fuel is contained in small spheres of impermeable graphite or beryllia, a break-up of the pressure vessel would allow them to scatter so that the core would no longer be critical and each pebble would retain its own fission products. Alternatively, even if the pressure vessel remained intact, the cooling circuit would almost certainly fail. In this case, the heat output would raise the temperature until the reactor melted. If a beryllium reflector were used, this would be first to melt and the small beryllia encased fuel pebbles would float in it. When the heat reached the pressure vessel, the resultant melt-down would allow the pebbles to be spread over a relatively large area and the pile would no longer be critical.

5.4. COSTS

Another aspect of the nuclear aircraft which is not always appreciated is the operating cost. In the first instance there must be very high research and development charges both for the nuclear power plant and the aircraft. The latter need not be much greater than for the conventional supersonic aircraft and the former could be associated with other power plant developments. It is not possible to make reliable estimates of these costs at present, but some assessment of fuel costs can be made. It is usually assumed that the very small fuel consumption is equivalent to an equally small, almost negligible cost. This is not so, as uranium is expensive. It has been quoted in the U.S.A. at £2,700 per lb. and, as mentioned earlier, a sortie may use 4½ lb. Re-processing is necessary after 10 per cent has been fissioned and this may cost £450 per lb. With these figures, the cost of nuclear energy delivered to the engine is about 0·12d. per h.p./hr. With kerosine at 1s. 2d. per gallon the cost of chemical energy is just about double.

6. Outstanding Problems

It was stated in the introduction that the nuclear powered aircraft was possible, and the succeeding sections have shown this to be true. They have also shown that there are a number of major problems. These can be divided between those which are developments of present experience, such as the engine mechanical design and the aircraft structural design, and those which require research into relatively unknown fields. The latter include highly rated cores and fuel elements, heat exchangers, shielding and safety.

The first two of these have to work at high temperatures and the success of any project will be in proportion to their operating temperatures. Their heat

TABLE V
SINGLE STAGE NUCLEAR SATELLITE ROCKET WEIGHTS

Component	*Weight lb.*	*per cent*
Structure	26,000	9·7
Reactor and Power Plant	17,000	6·3
Propellant	200,000	74
Payload	27,000	10
Total	270,000	100

transfer characteristics, structural strength and compatibility with coolants all need investigation in the highly rated conditions demanded. By using the open cycle one of these problems is discarded, but the importance of impermeable coatings for the fuel pebbles becomes even more significant. The production of these pebbles in small sizes and large numbers could be a vital factor.

Shielding is also critical because too exacting a requirement will swallow up most of the useful payload, but too little could involve dangerous radiation levels. Safety, especially in crash conditions, could also rule the whole project out unless new techniques are worked out. In addition there are many detailed problems to be studied. Examples of items which need investigation are the performance and design of helium turbo-circulators, engine and reactor control for starting, changing power and stopping, ground handling equipment and so on. An active programme on all these would be of advantage in the development of other nuclear projects and, if linked with them, need not be uneconomic.

7. Other Applications

Apart from turbojet propulsion, nuclear power has advanced sufficiently in recent years to be worthy of consideration for ramjets and rockets for long range missiles and for space vehicles. The Americans have active programmes under the code names PLUTO for ramjets, ROVER for nuclear rockets and SNAP for space auxiliary power. In addition many project studies have been stimulated by the successful satellite launchings. Some of these will be discussed briefly in order to complete the picture of nuclear power in flight.

7.1. HIGH THRUST ROCKETS

Large nuclear rockets might replace one or more stages of propulsion for launching space vehicles. For this purpose the reactor will operate, as in the gas turbine, as a source of heat energy for the working fluid. It will use an open cycle to ensure that the maximum gas temperature is achieved and hence the maximum performance. This performance is not limited by the chemical energy of the propellants, but only by the temperature which can be supported by the reactor and exhaust nozzle materials. This is the most important area for development because any low molecular weight gas will give a good performance. As an example, even water, heated to 3,000°C, would give a thrust of 25 per cent more than the current liquid oxygen/hydrocarbon fuel propellants at the same temperature. Better still, pure hydrogen would increase the thrust more than three-fold.

Performance of this order would permit single stage rockets of relatively low mass ratios to enter satellite orbits or even to escape into space. Calculations for such a rocket using hydrogen at 3,000°K. give a mass ratio of under 4: 1 and a payload of 10 per cent. The weight breakdown is shown in Table V. This indicates an all-up weight of the same order as the American Midas satellite launcher and an absolute weight placed into a 300 mile orbit more than five times greater.

Radiation during launching of this rocket might be unacceptably high, but could be overcome if used only as a second stage when well clear of the ground, following a chemical rocket first stage. Even this entails some hazard in the event of the first stage failing. This risk is present in any reactor system launching and a further problem may arise if re-entry from space occurs after use.

7.2. SMALL THRUST ROCKETS

Small rocket engines will be required for vehicles launched into orbit or space trajectories in order to correct or modify velocity and heading, or otherwise to change conditions. Nuclear energy may be applied to these indirectly through conversion to electric energy and thence by electric arc chambers, ion accelerators, or plasma jets to thrust.

The first of these merely heats the propellant in an arc discharge. It is possible to achieve fairly high gas temperatures and hence high specific impulse—of the order of 2,000 sec. Its efficiency, like all the electric conversion systems, is low, and over-heating of the electrode chamber may result.

The second system does not have the same heat difficulty. The propellant is ionised and then electrically accelerated to velocities of the order of 300,000 ft./sec. or more, that is, specific impulse is 40 times greater than that of normal propellants. Ionisation is brought about by passing cesium vapour over heated tungsten plates. The ions are then accelerated by some 20,000 volts d.c. The electrons stripped from the cesium must also be discharged separately so that they can neutralise the ion charge externally.

The third system is effectively a method of accelerating both ions and electrons in the same jet. This is arranged by inducing an electro-magnetic field to accelerate the particles by discharging a condenser across two electrodes and producing an arc. The current in the arc induces the magnetic field and their interaction produces a force in a direction at right angles to both. The plasma is accelerated and repeated discharges give a mean thrust equivalent to a specific impulse of nearly 20,000 secs.

7.3. AUXILIARY POWER SUPPLY

For operations in space, whether by instrumented or manned craft, power supplies are essential and the most convenient form in which to have them available is as electrical energy. For modest amounts storage batteries, solar cells, or chemical generators are possible, but for the increasing quantities likely to be demanded in future, nuclear reactor-generator systems will be essential. Radio-isotopes will supply small power demands through thermo-electric conversion, but for large

outputs a reactor supplying a turbo-generator will be used. This system will be basically similar for all the foregoing electric power systems and will include a compressor and turbine with similar design problems to the aircraft plant.

One of the major points is, however, that a closed cycle operation is obligatory and that heat rejection can only be by radiation in space. The radiator design assumes much the same importance as did the heat exchanger in the aircraft power plant, but it is necessary to stow it in a compact form until it is clear of the atmosphere. One interesting suggestion put forward in America is for a flexible radiator which can be wrapped around the cylindrical hull of the power plant and only unfurled in space. Some idea of the size can be gained from the power output of 1 MW (electric) at an overall efficiency of 13 per cent from an all-up weight of 10,000 lb. The radiator for this requires 17,000 sq. ft. to reject the 6·8 MW wasted.

8. Conclusions

In the past few years, reactor developments have confirmed earlier views that nuclear powered flight is technically feasible and they have gone some way towards overcoming some of the earlier difficulties. The open cycle turbojet and the closed cycle gas cooled reactor system both have possibilities of providing adequate power for sustained high altitude supersonic flight, although only with large aircraft. When shielding is not a vital factor, as in unmanned rockets, the weights become much less.

In both cases, the question of development in this country depends upon an assessment of our future role in world politics and technology. The precise benefits cannot be stated, but there should be sufficient advantages to justify a modest programme of research and development at this time. In conjunction with programmes on supersonic aircraft and high temperature reactors it could provide a relatively inexpensive, but none the less valuable, vantage point from which progress in any appropriate direction could be started.

Acknowledgments

I wish to acknowledge the help and advice of members of the Nuclear Power Group of The de Havilland Engine Co. Ltd. in preparing this paper and, in particular, of Mr. F. R. Bell and Mr. A. Baker, who carried out most of the engine and reactor calculations on which the paper is based. In addition I am grateful to Mr. C. W. Cleverdon of The College of Aeronautics for extensive references to the subject, some of which are included in the bibliography.

I also acknowledge the permission of my co-directors on the Board of The de Havilland Engine Co. Ltd. to publish this paper, and I wish to point out that the views expressed in it are personal and do not necessarily have any official support within the Company or elsewhere.

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DISCUSSION

B. W. Ludwig (Vickers-Armstrongs (South Marston) Ltd., Swindon, *Graduate*): It was heartening to hear that theoretical consideration was being given to nuclear propulsion for aircraft in this country, in view of the practical work which was being done in the United States. It was rather sad to think that they could fall behind in this subject as well as one or two others in the past.

It was apparent that the subject and the problems involved were extremely large and considering the nuclear power plant alone he would have thought the initial design estimate, which usualy proved to be too low, would be in the class of hundreds of mega-manhours. He wondered if Professor Baxter had, at any stage, considered a fast plutonium reactor? This would give a denser fuel yielding more neutrons per fission than uranium 235. The fast breeder reactor at Dounreay was advancing their knowledge on plutonium.

Early in the lecture Professor Baxter mentioned the possibility of bismuth as a coolant. This could be interesting; bismuth 209 was transmuted to polonium 210 which, being a high energy $\alpha-$ emitter, would then be usable as a heat source for a direct conversion device. If Professor Baxter eventually built a bismuth cooled reactor they, at Vickers, might be able to apply some of the polonium 210 to a small version of the Snap-3 generator which they had built.

On a rough estimate it appeared that the flight path, before refuelling, would be something like 90,000 miles. This meant that an aircraft could fly around the world very nearly four times, which would be quite an advancement on present performance. Would this mean, eventually, that passengers wishing to alight somewhere between London and . . . London, would have to be parachuted off or dropped out on some form of flying saucer?

Professor Baxter had mentioned the melt down of the beryllium to disperse the core. He wondered if the toxicity hazard of beryllium would be greater than the actual hazards of radiation from the reactor?

Professor Baxter: He had to answer these questions as an engineer and not as a nuclear physicist. Nevertheless, the nuclear problems had been studied and, in particular, consideration had been given to alternative reactor systems. On the whole these had favoured the gas cooled uranium fuelled system and so the present exercise had been limited to that. The use of liquid metal cooling tended to a heavy design and the production of polonium 210 which was so very radio-active would introduce additional problems. On the other hand, beryllium toxicity in a crash would not be so likely to disperse in dangerous concentrations as widely nor persist as long as radio-activity such as that present in polonium or the reactor fuel.

Regarding passenger flights, he had not considered such operations at this stage. In Fig. 7, for instance, the cabin was only 20 ft. long by 7½ ft. diameter. If passengers would accept such limited accommodation, perhaps they would also be willing to be dropped out at their destination! Ultimately he would assume that civil nuclear-powered aircraft would operate normal long distance flights in the conventional manner, or possibly some new technique would be developed, like a glider slip cabin.

J. F. Barnes (National Gas Turbine Establishment, *Graduate*): He should like to endorse the plea that the liquid metal cooled reactor should receive further study. It was well known that liquid metals were highly corrosive. However, it would be imprudent to state categorically that corrosion problems would always prohibit the use of liquid metals in a reactor for aircraft propulsion, if only for the reason that one could never be certain of the improvements in materials and technology which might come in the next decade or so. The relatively small size of a liquid metal cooled fast reactor core would probably permit a lighter shield than that needed for a gas cooled reactor. In fact the saving in shield weight might be so great that it would be permissible to reduce the turbine inlet temperature of the jet engines and hence the operating temperature of the reactor. Although this would lead to an increase in engine size for a given thrust, the overall power plant weight might still be less than the weights of systems using either the direct air cooled open cycle or the indirect gas cooled cycle. From Professor Baxter's lecture, the power plant weights of the direct and indirect systems appeared to be very similar. Any improvement in power plant weight obtained by using a liquid metal cooled fast reactor must be coupled with the fact that the very good heat transfer properties of a liquid metal, such as lithium, would allow the operating temperatures of such a fast reactor to be well below those required for a gas cooled reactor.

He would like to ask one question which was really related to space flight applications of a gas cooled nuclear reactor. Professor Baxter had said that power densities in aircraft propulsion reactors would have to be of the order of ten megawatts per cubic foot. Would he agree that for a rocket application it would be desirable to increase this power density to a value of the order of one hundred megawatts per cubic foot and that ultimately the limiting factor might be thermal stresses generated by temperature differences existing in the reactor fuel pebbles, which would of necessity have to be very small indeed?

Professor Baxter: He agreed that one must not be too categorical about future reactor developments, but because gas turbines would always be demanding higher temperatures, he thought they should aim for a reactor that had the potential for coping with this. He doubted if the liquid metal cooled reactor would be able to compete ultimately and certainly, when rocket propulsion was considered, this would be true. A rocket system would almost certainly be an open cycle arrangement, so why not start with a gas cooled reactor and not a closed cycle liquid cooled one?

With regard to the specific output for a rocket, it was not necessary to go to figures nearly as high as 100 MW per cu. ft. although, naturally, the greater the power density the better from an overall volume point of view. In fact, the figures of Table V were based on outputs of the same level as for aircraft propulsion. Greater outputs would have certainly depended upon high temperature gradients and thermal stresses could have been a limitation as suggested.

G. E. Preece (*Associate Fellow*): As Professor Baxter had indicated, technical feasibility was now generally accepted although the outstanding technical problems would require considerable effort before satisfactory solutions were found. While this conclusion applied for subsonic application, the case for supersonic aircraft was marginal, since the heat ratings necessary were exceptionally high and would require a considerable extrapolation of present day nuclear experience.

With regard to the basic system outlined—the closed cycle helium system, a comment on how this was arrived at might be appropriate in view of the alternative proposals already raised in discussion. The two systems being developed in the U.S.A. were the open air cooled cycle and liquid metal cooled type. Their assessment of the latter had been that since alkali metals all suffered from the disadvantage of being pyrophoric* it would be undesirable to add this to the considerable nuclear hazards which already existed. The heavy metals were ruled out due to their excessive weight and the production of polonium in the case of bismuth referred to by another speaker was to be regarded as a most undesirable feature due to the radio-active health hazard associated with this material.

*Spontaneously combustible in air.

The key problem which remained was that of safety and no system proposed so far provided a satisfactory solution. Consideration had been given to containing the whole reactor in a series of laminated shells such that on impact with the ground the shock would be absorbed progressively through the shells. Another suggestion was to use metal parachutes which would open in emergency and so reduce the impact to a safe value but all such ideas were of doubtful practicability.

The strongest case for undertaking work in this particular field was that it would act as a big incentive to the development of really compact power reactors which could be applied in the first instance for ship propulsion and power generation.

One application that possibly should not be ignored was for hovercraft. This was obviously midway between the ship and the aircraft application and the safety problems might be solved to the satisfaction of the appropriate authorities.

Professor Baxter: He was glad to have Mr. Preece's comments which reinforced and amplified the answers he had already given.

The arguments about liquid or gas cooling of reactors were reminiscent of those concerning air and liquid cooling of piston engines axial or centrifugal compressors in gas turbines, solid or liquid propellants in rockets and so on. Each had its merits and drawbacks and the right decision might depend upon special circumstances.

As far as the crash hazard was concerned, there was no question but that this was a vital problem. At the present time no absolute solution could be seen and the best effort was to ameliorate the consequences. This might be by confining the risk to the sea, as suggested with a hovercraft. This, in itself, was an alternative craft for nuclear propulsion, but he believed that space rockets might prove the first serious application. Here the crash risk would occur relatively infrequently and could be catered for by launching over sea areas.

J. Cuss (Chief Stressman, Gloster Aircraft Co. Ltd., *Associate Fellow*): The question of safety had been very much highlighted in the lecture and of course it was not safe if a normal aircraft dropped on a highly populated area. Could Professor Baxter describe more fully the real hazards in this matter of crashing and having the engine with one at the same time? Presumably it was nothing like a hydrogen bomb. He wondered if Professor Baxter could say whether it was more widespread, whether it was more lethal? On the subject of trying to do something about it before one crashed, he imagined that even in a nuclear powered aircraft one would have some warning of a crash in the same way that one did in other aircraft, so one would have thought that jettisoning the engine with explosive bolts and letting it down on some sort of colossal parachute would present an opportunity to get the power plant down in one unit without its breaking up.

Professor Baxter: The main danger resulting from a crash was neither that associated with a conventional aircraft nor that from a nuclear bomb. It was that there might be a release of much radio-active material which would be vaporised and could drift in the form of a cloud, leaving a dangerous trail behind it some miles wide and many more in length. This might contaminate ground or buildings and make them untenable for a considerable period.

W. A. C. Kendall (Lecturer, Swindon College *Associate Fellow*): It had been a pleasure to welcome to Swindon the President and Secretary of the Society and to have had a Main Society lecture delivered there by Professor Baxter.

He and he was sure the members were grateful to Professor Baxter for having come to Swindon and for showing them how, undaunted by the immensity of the problem facing him, he still, nevertheless, probed on in the true scientific spirit to solve these problems which they as engineers knew would ultimately be solved. It was perhaps no coincidence that the next lecture to be delivered to the Branch was "Parachutes and Parachute Design"; whether that was intentional or not he did not know. One other point he would make was that when Professor Baxter came to build this atomic engine he hoped the Professor would remember that they had an activity in this area concerned with nuclear physics and they would be pleased to help him out.

J. C. Chicken (*Associate Fellow*): *Contributed.* He would first like to congratulate Professor Baxter on his paper, which did much to make nuclear powered flight look a feasible and even an economic proposition. It was to be hoped that his paper would be the starting point for a detailed study of the problems of nuclear powered flight.

Perhaps the most important feature that required more detailed examination was the question of cost. While Table III showed that nuclear power would give 100 per cent increase in payload as compared with a conventionally powered aircraft, and under the heading of costs nuclear energy was quoted as being half the price of chemical energy, these figures would require a very detailed design study to establish if they were realistic. Further experience with the reactor to be used would be essential to establish the cost of this part of the project.

As the landing weight would be the same as the take-off weight, it implied that stronger and longer runways would be required. However, if the aircraft were designed for vertical take-off it would reduce the amount of civil engineering work required to support the operation of nuclear powered aircraft. Further, as there might be some restriction on the places from which a nuclear powered aircraft would operate, it would be easier to find sites suitable for vertical take-off aircraft than for an aircraft using conventional landing gear.

It seemed undesirable to have a combustible fuel such as kerosine as shielding, because in the event of a crash this could start a fire which might damage the reactor in such a way as to give rise to a release of fission products.

Taking the last point a little further, it would seem to be advantageous to combine the reactor and shielding in such a way that the reactor was virtually indestructable, the implication of this being that in the event of a crash fission product release would be impossible. This would mean that fuel element design would be simplified as it would no longer be necessary to design for fission product retention in the event of the reactor bursting. Nevertheless, the design of the fuel element for an airborne installation did pose many interesting problems.

As it was proposed to have graded shielding, some thought might have to be given to putting portable shielding over the reactor to facilitate servicing operations on the ground.

Professor Baxter: He agreed that detail studies were necessary to be sure of the weights and payloads he had quoted and some revision would occur. This was particularly so if the suggestion to use vertical take-off was adopted. At the present time, the chemical fuel consumption necessary for this technique would be about 1½-2 per cent of the all-up weight per minute of operation. Thus the available payload would be quickly reduced. Nevertheless such a system did have advantages and ought not to be dismissed out of hand.

Regarding costs, he felt confident that any studies would show lower nuclear fuel costs and these might become still lower in the future. Against this there were many other capital and operating costs which would be greater, at least in the early days.

The problems associated with a crash had been covered in the earlier discussion and, while the ideal of a crash-proof reactor was the designer's dream, he feared this impossible without making the system too heavy to leave the ground at all.

Jet Lift Engines and Power Plants for V.T.O.L. Aircraft

BY

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(Chief of Preliminary Design, Aero Division, Rolls-Royce Ltd.)

1. Introduction

The Short SC.1 V.T.O.L. Research Aircraft, using four special Rolls-Royce RB.108 jet lift engines, which made its first flights in 1959 heralds a new method of taking-off and landing which may revolutionise the operational flexibility of aircraft of the future. The Short SC.1 is the result of six years research and development by Short Brothers and Harland Ltd., who built and developed the aircraft, and Rolls-Royce Ltd. who designed and developed the special light weight turbojet engines which support the aircraft during the V.T.O.L. phase and which are shut down as soon as the aircraft has attained wing borne flight by the horizontal thrust from its separate propulsion engine. The SC.1 is shown in hovering flight in Fig. 1.

We should now be entering a phase when real operational aircraft are being planned using this principle. From the military point of view, the ability to take-off and land vertically offers a considerable tactical advantage, permitting wide dispersal and also extending the penetration ranges. In the civil field there is the possibility of a fast V.T.O.L. city centre jet liner; this project will follow the military application of jet lift. This is because civil aircraft have the additional problem of achieving acceptable operating economics and noise level, and there is not yet a satisfactory solution to either of these factors. Then there is the V.T.O.L. supersonic air liner envisaged by Dr. A. A. Griffith which is considered as the ultimate goal for the aircraft and engine designer alike.

The feasibility of any of these projects depends primarily on achieving the lowest possible weight for the lift engines and their installation. The RB.108 engines in the Short SC.1 give eight pounds thrust for each pound of weight, but this figure must be improved if an operational aircraft with a useful payload is to be built. If the thrust per unit weight could be doubled the aircraft designer would be able to evolve a really useful operational military V.T.O.L. aircraft. An aircraft which does not have to take off and land on its wings offers a completely new opportunity to the aircraft designer. We feel that, if tackled fundamentally, and not from the point of view of adapting or modifying an existing aircraft, it should be possible to reduce aircraft structure weight and control complexity in order to compensate in part for the weight of the lift engines. There is a parallel here in the design of the lift engines themselves, for in formulating the design of the RB.108 and later lift engines we have deliberately ignored operating conditions which determine the design of turbojet propulsion engines, and taken account only of the special conditions of operation of lift engines. This is characterised by engines operating for a few minutes per flight only, and perhaps for as short a period as one minute at full power.

We have had to consider in our project studies different aircraft configurations to guide us in our engine planning, and to provide us with a basis for the research and development into all the power plant problems associated with jet lift engines, both pure turbojet and turbofan engines. The turbofan engine studies have been an important part of these investigations.

The history of work on light weight engines for V.T.O.L. aircraft has been covered in Ref. 1, and this paper will discuss some results of project investigations and outline work on jet lift V.T.O.L. problems associated with the installation of lift engines in aircraft projects which may be considered feasible in the immediate future.

2. The Composite Power Plant

The Short SC.1 is an example of an aircraft designed on the principle of the "composite power plant" in which special light weight engines are installed in the aircraft for lift during take-off and landing, and a separate propulsion engine is installed having the thrust and performance characteristics required to suit the particular aircraft operation. The composite power plant allows the aircraft designer a good deal of freedom in choosing a layout best suited to the particular flight mission. For example, a narrow delta configuration may be selected to reduce structure weight, since with a V.T.O.L. aircraft take-off considerations no longer compromise the wing design. If the mission calls for supersonic speed the minimum frontal area will be required. There is no powered lift system which will be universal to all aircraft types, the optimum lift system will be dictated by the specific aircraft duty.

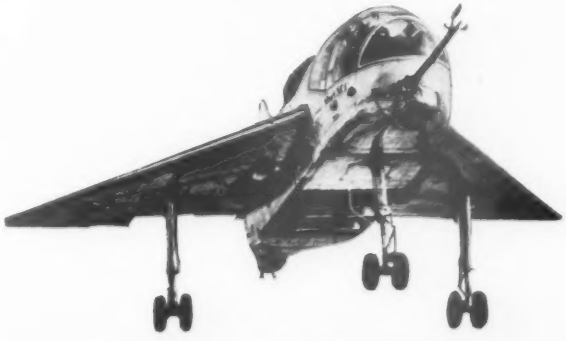

FIGURE 1. Short SC.1 aircraft in hovering flight.

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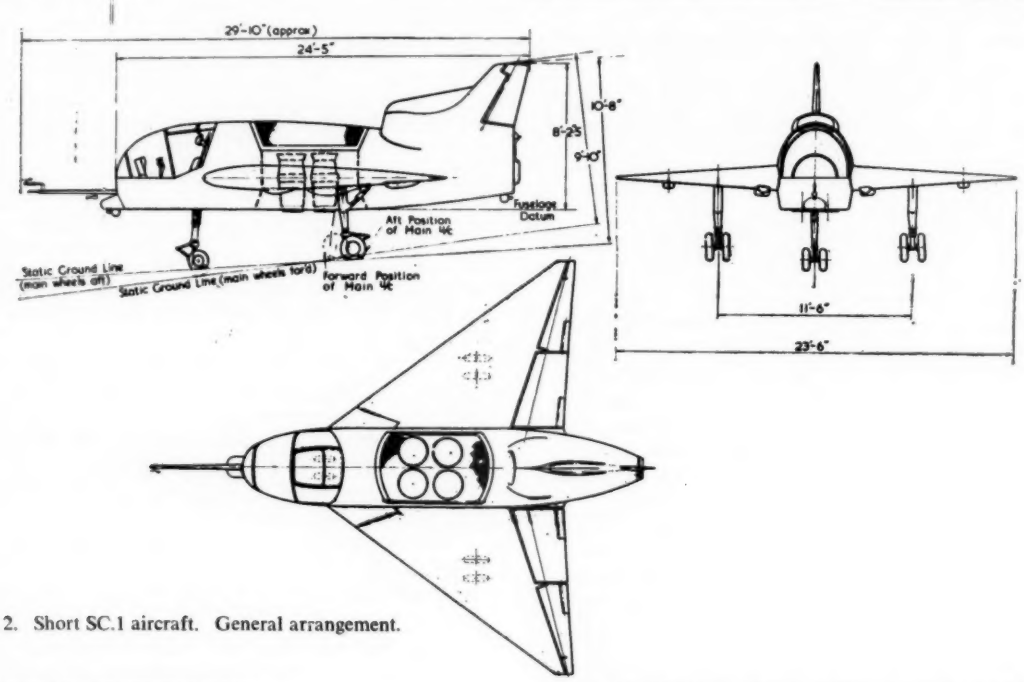


FIGURE 2. Short SC.1 aircraft. General arrangement.

2.1. AIRCRAFT CONFIGURATIONS

Let us consider examples of aircraft designs which can be regarded as feasible in the immediate future, and where all the engineering problems involved in the associated power plant can be considered as capable of solution using existing test data, or from a reasonable extrapolation of existing test data based on present experiment and research work.

This rules out the more unorthodox aircraft designs which have been considered from time to time, such as aircraft with tandem wings, lift fans installed in the wings, and flying wing designs in which passengers and lift engines are installed side by side. The difficulty with such schemes is that new aerodynamic problems are introduced at the same time as the new lift power plant and, however good the technical case, the overall risk involved in choosing a completely unconventional layout appears to be too great at this time. Nevertheless, the engine designer still looks hopefully to the aircraft designer for an elegant solution to the S/V.T.O.L. jet lift aircraft problem, and this applies particularly to transport aircraft. Meanwhile the engine designer continues to work to achieve lower engine and power plant weights in the belief that ultimately a really good configuration will emerge.

The two classes of aircraft considered are described below.

2.2. STRIKE AIRCRAFT

This is a short to medium range strike aircraft carrying about 10 per cent military load, cruising at high subsonic speed at sea level. If a supersonic capability at altitude is also required, reheat will be needed on the propulsion engine, and the aircraft weight will increase.

Two types of layout are shown in Figs. 3 and 4.

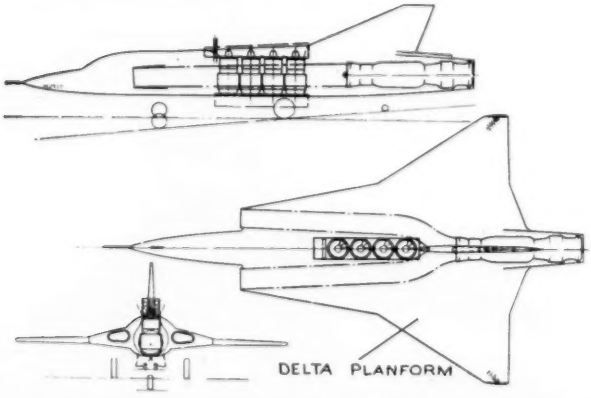


FIGURE 3. Strike aircraft delta configuration. 4×6,000 lb. thrust lift engines. 1×11,000 lb. thrust by-pass propulsion engine with or without reheat.

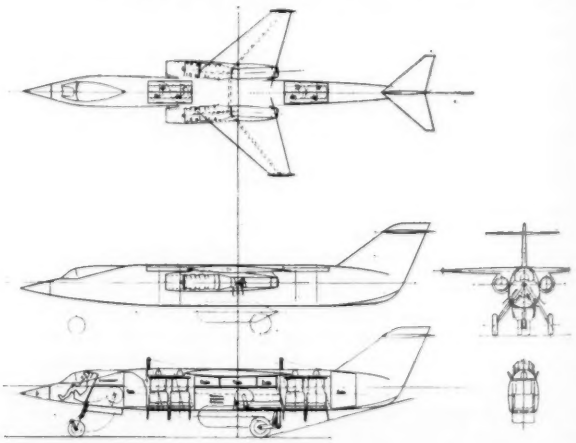


FIGURE 4. Strike aircraft. Swept wing configuration.

Fig. 3 shows an aircraft with delta type plan form with four lift engines arranged in the centre, and one efficient by-pass propulsion engine installed behind the lift engines at the rear. Fig. 4 shows a higher aspect ratio aircraft in which four lift engines are installed in two pairs at the front and rear of a central weapons bay. In this case propulsion is by two pure jet engines installed on each side of the aircraft at the wing roots, and if required each engine can be equipped with jet deflection to give additional lift thrust acting close to the aircraft centre of gravity during take-off. In both cases aircraft stability in hover and transition is effected by control jets in the wing tips and fuselage, fed by compressed air from the lift engines which are specially designed for the purpose. The control jet thrust is regulated in accordance with the signals from an auto-stabiliser.

The delta configuration follows closely the layout adopted for the Short SC.1 (Fig. 2) and does not present any particularly difficult new problems. This scheme is really a refinement of the Short SC.1 with lighter lift engines and a much more efficient propulsion engine.

Although the second configuration is new, there is nothing in this layout which is not capable of an engineering solution. The pitching moment arising from an engine failure will be greater than for the delta layout, and as we consider that a lift engine failure should be allowed for, this arrangement will require a greater installed lift thrust/weight ratio. The two pure jet propulsion engines will be appreciably lighter than the by-pass engine of the delta layout, but this will be offset by their higher fuel consumption.

2.3. TACTICAL TRANSPORT OR FREIGHT AIRCRAFT

We have in mind an aircraft of about 100,000 lb. take-off weight which can carry a payload of 20,000 to 30,000 lb. for ranges of the order of 500 n. miles cruising at 300 to 400 knots at altitudes up to 20,000 ft. The aircraft may have V.T.O.L. or S.T.O.L. capability, and for the larger payloads would use existing runways. For a military aircraft, noise standards would not be of great importance.

Two practical configurations are illustrated in Figs. 5 and 6. In each case the lift engines are installed in two wing pods. In Fig. 5 there are 32 pure jet lift engines and propulsion is by two Rolls-Royce Tyne turbopropeller engines. In Fig. 6 we show 20 turbofan lift engines producing much less jet noise and with propulsion by two or four efficient by-pass engines of the Spey type. Alternative combinations and numbers of these lift engines and propulsion engines are possible with the same general aircraft configuration. In the case of Fig. 6 it would be possible to equip the propulsion engines situated on the wings with variable angle jet deflectors to augment the lift thrust, and assist acceleration to transition speed. All, or a proportion of, the lift engines can be designed to tilt or be provided with swivelling nozzles to give extra propulsive or retarding thrust during acceleration and deceleration transition, and for manoeuvre.

An important practical advantage of this layout is that aircraft control can be maintained in hover and transition by differential throttling of the lift engines to modulate jet thrust both for roll and pitch control. Yaw control can be by differential pitch control of the turbopropeller engines, or by differential control of the lift engine swivelling nozzles. While air jet control is quite practical for the small strike aircraft described in Section 2.2, because of their small roll and pitch inertia, this method has proved difficult on large aircraft because of the large quantity of control air required from either the lift or the propulsion engines, and the complexity and weight penalty of ducting this air to the extremities of the aircraft at a considerable distance from the engines. The quantity of control air can be reduced by the use of control turbofans to augment the control nozzle thrust, but this increases the complexity of the installation still further, especially as it is considered that these turbofans would have to be duplicated to cover the possibility of mechanical failure.

The aircraft configurations illustrated, and which are referred to throughout the paper, have been selected from many schemes that have been studied.

3. Thrust Required for Short and Vertical Take-Off

The claim is often made that with an S.T.O.L. system, there is an appreciable saving in installed thrust

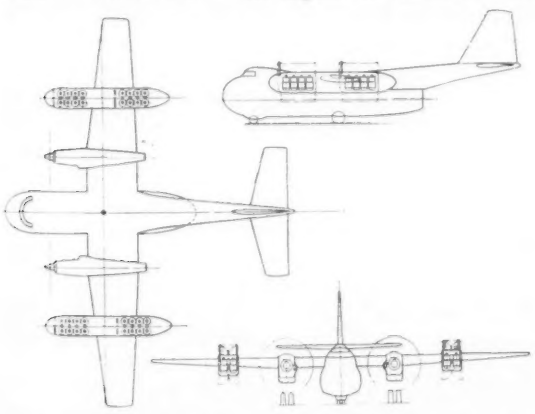


FIGURE 5. Tactical freight aircraft. 32 turbojet lift engines each giving 4,750 lb. thrust, and two Tyne turboprop propulsion engines.

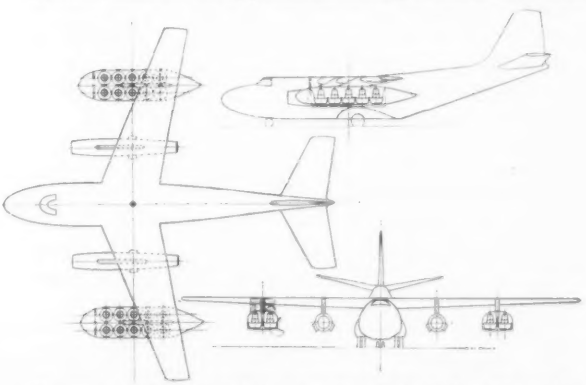


FIGURE 6. Tactical freight aircraft. 20 turbofan lift engines each giving 6,500 lb. thrust, and two 15,000 lb. thrust turbojet propulsion engines with jet deflection.

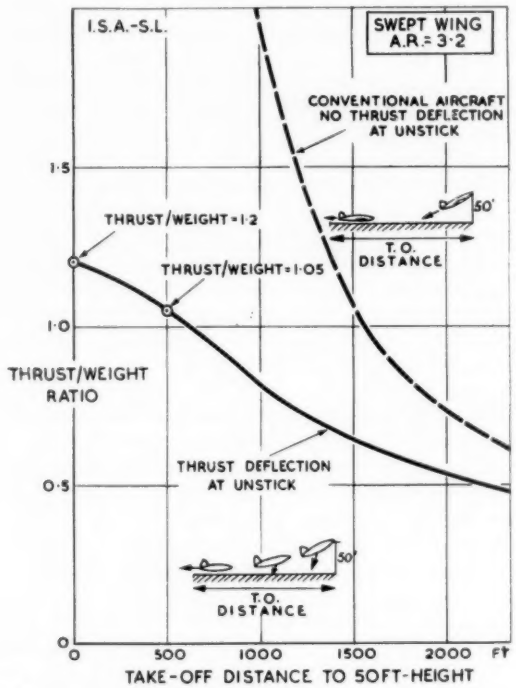


FIGURE 7. Strike Aircraft: Static thrust/Take-off weight ratio required for take-off.

compared with V.T.O.L. Direct jet lift cannot be discussed without dealing with this point. The installed thrust required will now be considered for conventional, short, and vertical take-off. There has been a good deal of argument as to what conditions should define S.T.O.L., and the conclusions arrived at from a comparison of S.T.O.L. with V.T.O.L. depend upon this definition. In this paper S.T.O.L. is defined as take-off and landing in 500 ft. horizontal distance to or from 50 ft. height. For these calculations a strike aircraft having the plan form illustrated in Fig. 4 was assumed.

Figure 7 gives the installed thrust/take-off weight ratio required against horizontal distance to reach 50 ft. height for the conventional take-off procedure with all thrust acting horizontally. For a distance of 1,500 ft. to clear a 50 ft. screen the thrust required would slightly exceed the weight, and for 1,000 ft. it would have to be very nearly twice the weight. Obviously, for an S.T.O.L. operation of only 500 ft. the engine or engines must provide a vertical component of thrust to assist the lift from the wings.

The shortest take-off would be achieved if all the installed thrust were used horizontally for acceleration during the ground roll, and then suddenly deflected downward at unstick, which is at approximately 60 knots. The deflection angle would be less than 90° since a thrust component along the flight path would be needed to prevent the aircraft decelerating during transition and climb. Assuming 0·2g normal acceleration during transition and allowing a finite time for thrust deflection, the thrust/weight ratio required to reach 50 ft. in 500 ft. is shown in the lower curve of Fig. 7 to be 1·05.

Figure 8 shows the take-off history for 500 ft. distance to clear 50 ft. The decision to lift the nose and deflect the thrust is made about three seconds after start of roll, and the screen is cleared in seven seconds with the aircraft at a dangerously low forward speed. Such a manoeuvre would almost certainly require supplementary pitch and roll control moments to assist the aerodynamic controls, and these may have to be automatic.

The thrust/weight ratio required for vertical take-off to ensure satisfactory manoeuvrability during take-off and landing is assumed here to be a minimum of 1·20, and this further assumes that the thrust vector can be rotated as required.

From this it is seen that if a really short take-off is required, the installed thrust needed in the aircraft is not so very much less than for V.T.O.L. If V.T.O.L. is designed for at the outset, landing and take-off will be safer than S.T.O.L. as defined in this paper.

3.1. TAKE-OFF AND LANDING OF V.T.O.L. AIRCRAFT

The method of take-off and landing of a V.T.O.L. aircraft depends upon the ground surface available. Clearly, an S.T.O.L. aircraft requires a runway or a flat field. A V.T.O.L. aircraft offers much greater flexibility in take-off procedure. If prepared ground is available, such as an area of concrete or road, the aircraft can take off (or land) vertically from a given position provided this is done quickly to minimise the effects of hot gas ingestion into the engines. Alternatively, the aircraft can roll forward along the ground at a modest speed, say 30 knots for a distance of 100 to 150 ft., before the engine or engines are opened up to full power for the vertical take-off. This technique would be the

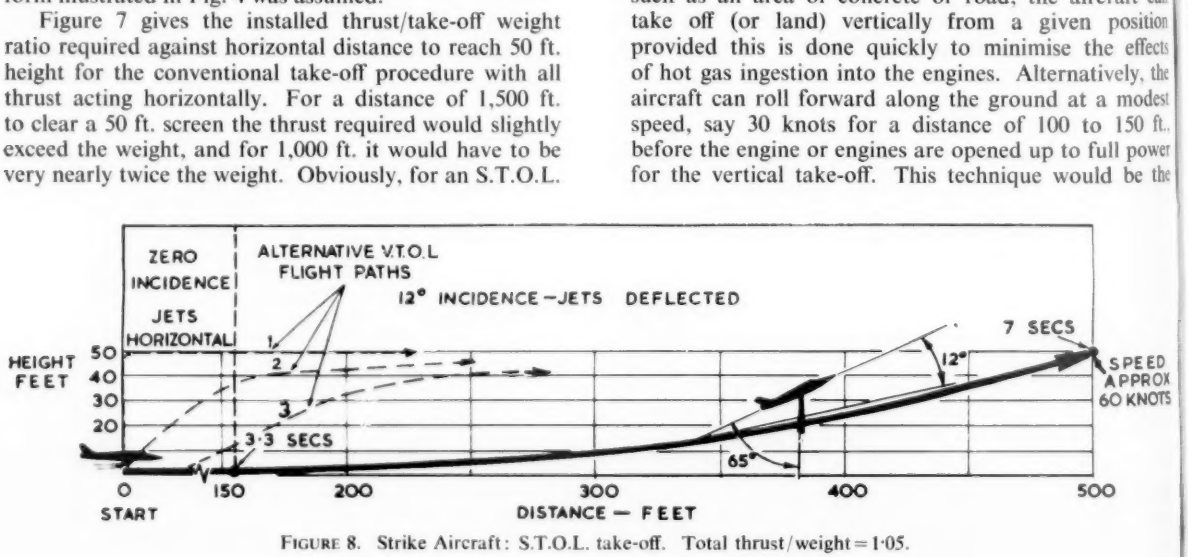


FIGURE 8. Strike Aircraft: S.T.O.L. take-off. Total thrust/weight = 1·05.

TABLE I

Power plant arrangement for S.T.O.L. aircraft	*Composite power plant* 1	2	*Single engine power plant* 3
Propulsion engine type	Pure jet	By-pass	By-pass
Pressure ratio	7	18	9
By-pass ratio	0	0·95	1·6
Specific weight lb./lb. (engine only)	0·11	0·20	0·14
Static thrust/aircraft take-off weight (installed)	0·46 (includes 8% deflection loss)	0·46	1·05
Booster engine type	Pure jet	Pure jet	—
Assumed specific weight lb./lb. (engine only)	0·06	0·06	—
Static thrust/aircraft take-off weight	0·59 (includes 8% deflection loss)	0·59	—
Total installed thrust/weight	1·05	1·05	1·05
Aircraft weight breakdown—%			
Structure including controls etc.	29·9	30·3	28·1
Power plant including intakes and systems	19·6	25·7	25·5
Fuel (20% allowances and reserve)	33·8	24·3	37·6
Military load	16·7	19·7	8·8
Take-off weight	100	100	100
Take-off weight ratio to meet mission 400/600 n. miles at S.L.	1·17	1·0	2·24

one to adopt if level ground in the form of a concrete strip, road or field were available, as it will prevent ingestion of hot gas or debris into the engines. Tests are at present being conducted to determine the effect of rolling speed, jet velocity and jet height and angle to the ground on gas recirculation and movement of debris. Although the exhaust velocity and temperature from turbofan engines are much lower than for the turbojet-lift engine, the greater volume of gas for a given thrust may offset these advantages.

When prepared ground is no longer available, the S.T.O.L. aircraft cannot operate. The V.T.O.L. aircraft may still land and take off from a small area of concrete, or from a shallow platform of the type developed for the Short SC.1. This can be set down on unprepared ground, such as a ploughed field.

It is conceivable that strike aircraft, in addition to operating from the ground, may take off from a mobile platform used for aircraft dispersal at the beginning of hostilities. After performing its mission, the aircraft would return and land wherever it was convenient to do so. The Short SC.1 has recently demonstrated landings on a grass field.

Alternative V.T.O.L. flight paths are shown in Fig. 8. The time from take-off to attaining wing-borne speed will be half to one minute, depending on the aspect ratio and wing loading, and full engine power will be required for perhaps only half this time.

3.2. COMPARISON OF SINGLE AND MULTIPLE ENGINE POWER PLANTS IN S.T.O.L. STRIKE AIRCRAFT

Having established that a thrust/weight ratio of 1·05 is required for S.T.O.L. (Section 3.0), this can be obtained in two ways by:

(1) A single engine power plant with means for deflecting the thrust.

(2) A composite power plant having separate propulsion and booster engines all of which have means for deflecting the thrust.

For (1) the power plant is a compromise. It is much too large for the subsonic cruise, has a medium pressure ratio to keep the specific weight low, and a high by-pass ratio to reduce the fuel consumption. For (2) the lightest possible turbojet booster engines are used, with a propulsion engine or engines matched in thrust to the cruise or manoeuvre requirements. This propulsion engine may be a pure turbojet of low specific weight, or a high pressure ratio by-pass engine having the lowest possible fuel consumption for a low level subsonic strike mission.

The aircraft was assumed to have the general particulars given in Section 3.0, and to have a structure weight, including systems and controls, of approximately 30 per cent of take-off weight. Estimates of (engine+fuel) weight and take-off weight were made for the three cases to meet the mission, and the data is summarised in Table I.

The composite power plant with light weight booster engines leads to a much smaller aircraft for the mission than if a single engine is used. Even if a much lower specific weight of 0·13 lb./lb. is assumed for the installed weight of a single engine including jet deflectors, the estimated take-off weight is still a good deal higher than for the composite power plant. Table I also shows that it is better to use the low specific fuel consumption, high pressure ratio by-pass engine for propulsion than the lighter turbojet engine. The static thrust/take-off weight ratio assumed for the propulsion engines should cover a high "g" steady level turn at high subsonic speed at sea level without reheat.

The main reason for these conclusions is show Fig. 9 which gives curves of specific fuel consumption against the ratio of thrust for level flight/take-off weight for the low level mission referred to. The specific fuel consumption of the single engine power plant is quite good in the vicinity of maximum rating, and lies between the corresponding values for the pure jet and by-pass

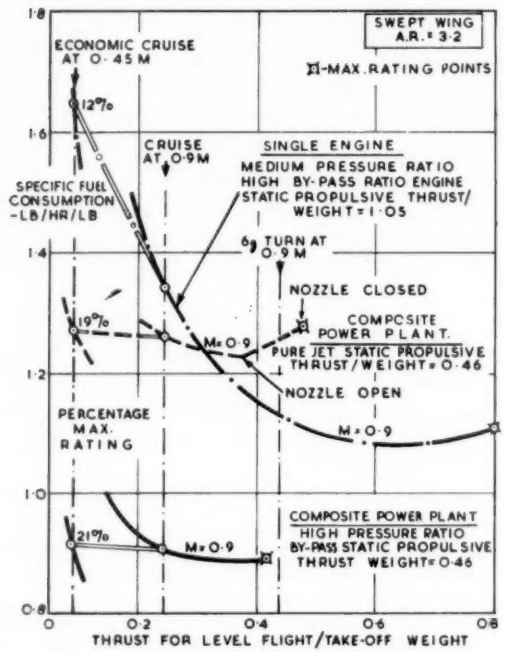


FIGURE 9. Strike Aircraft: Specific fuel consumption on low altitude mission. Total thrust/weight = 1·05.

engines of the composite power plants given in Table I. However, the large thrust required for S.T.O.L. in the single engine case makes the engine much too large for the other phases of the mission, and so it must be throttled back for cruise with consequent deterioration in specific fuel consumption. At economic cruise Mach number 0·45 the single engine is throttled down to 12 per cent of its maximum rating, whereas with the composite arrangement the propulsive engines would be throttled back to about 20 per cent of maximum rating. At these conditions the single engine has considerably higher specific fuel consumption than the other versions.

With a composite power plant the possibility arises of deflecting the thrust of the booster engines only. We have considered this case, and as would be expected, the total installed static thrust/take-off weight ratio required is higher, and compared with the previous figure of 1·05, a value of 1·4 is now required. On the other hand the propulsion engine thrust deflectors and associated equipment can be omitted. Assuming that the propulsion engine is the by-pass engine given in Table I, the aircraft take-off weight to meet the mission came out nearly 20 per cent greater. Hence there is a strong case for deflecting propulsive thrust as well as booster thrust, but this depends upon the aircraft layout.

Having established the superiority of the composite power plant for S.T.O.L., the composite power plant will now be considered applied to a strictly V.T.O.L. application.

3.3. MULTIPLE ENGINE POWER PLANT IN THE V.T.O.L. STRIKE AIRCRAFT

Many power plant arrangements are possible, but they can be divided into two main types, namely:

1. Those in which the propulsion engine thrust is deflected into the vertical direction to assist the vertical thrust of the light weight booster or lift engines. The power plant shown in Fig. 4 is an example of this type.
2. Those in which the propulsion engine thrust is not deflected, and in which the whole of the lift thrust is provided by the light weight booster or lift engines. The power plant shown in Fig. 3 is an example of this type, and this follows the principle of the Short SC.1.

TABLE II

Composite power plant for S.T.O.L. and V.T.O.L. aircraft	V.T.O.L. *Without propulsion eng. thrust deflection* 1	V.T.O.L. *With propulsion eng. thrust deflection* 2	S.T.O.L. *All engines with deflection* 3
Propulsion engine type	By-pass	By-pass	By-pass
Pressure ratio	18	18	18
By-pass ratio	0·95	0·95	0·95
Specific weight lb./lb. (engine only)	0·20	0·20	0·20
Static thrust/aircraft take-off weight (installed)	0·75 (No deflection loss)	0·69 (Includes 8% deflection loss)	0·46 (Includes 8% deflection loss)
Jet deflection (included in installation weight)	No	Yes	Yes
Booster engine type	Pure jet lift vertical engines	Pure jet lift vertical engines	Pure jet
Assumed specific weight lb./lb. (engine only)	0·06	0·06	0·06
Static thrust/aircraft take-off weight	1·20	0·51	0·59
Total installed thrust/weight	1·95	1·20	1·05
Aircraft weight breakdown—%			
Structure including controls etc.	17·9	18·1	30·3
Power plant including intakes and systems	35	30·6	25·7
Fuel	28·6	28·6	24·3
Military load	18·5	22·7	19·7
Take-off weight	100	100	100
Take-off weight ratio to meet mission 400/600 n. miles at S.L.	1·06	0·865	1·0

The second type has a greater total installed thrust than the first, and the greater basic engine weight, but the first type must include the bulk and weight of jet deflectors, and care must be taken to locate the engines and design the deflectors so that the thrust vector passes through, or near to, the centre of gravity to avoid large trim changes. This can be a severe limitation. All types may provide for the deflection of the lift engine thrust to give a horizontal component to assist accelerating and decelerating transition. The weight penalty for this is small provided the angle is less than $\pm 30°$ from the vertical.

When estimating the take-off weight of the V.T.O.L. aircraft to do the mission (Section 2.2) we selected a high aspect ratio delta plan form. High lift devices for landing are unnecessary and have been omitted. Flaps and their mechanism are also omitted, and an undercarriage of lighter design without main brakes was assumed. This led us to believe that a structure weight of 18 to 20 per cent of take-off weight was possible compared with 28 to 30 per cent for the S.T.O.L. aircraft in Table I. This is the factor which requires verification by the aircraft designer. On this basis the data given in Table II was derived and the data for the by-pass engine version of the S.T.O.L. composite power plant from Table I is included for comparison.

Because the V.T.O.L. aircraft has a low aspect ratio, the propulsive thrust to weight ratio has been increased by 50 per cent to maintain a high "g" capability in a steady level turn at high subsonic speed.

Our conclusion is that it is possible to install sufficient booster or lift thrust to achieve V.T.O.L. without the assistance of the deflected thrust from the propulsion engine, and a V.T.O.L. aircraft of this type need be only a little heavier than the S.T.O.L. aircraft with the composite power plant, both meeting the same mission requirement.

3.4. MULTIPLE ENGINE POWER PLANT IN THE TACTICAL TRANSPORT OR FREIGHT AIRCRAFT

We believe that the same general conclusions with regard to aircraft structure weight should apply to a large V.T.O.L. transport aircraft if it were of the delta configuration with integrated power plant proposed by Dr. A. A. Griffith (Fig. 10). We would like to see this concept thoroughly investigated by the aircraft designer. However, at this point in time, we realise that this type of aircraft involves the combination of so many new features at once—aerodynamics, new structure and materials, and new multiple power plant with new systems, that it may be too big a step to take. That is why the tactical freight aircraft illustrated in Figs. 5 and 6 are proposed as a possible immediate step. However, this configuration with pods of lift engines giving V.T.O.L. capability, combined with normal take-off from runways when fully loaded, gives little or no scope for reduction of structure weight, and so the penalties in payload and range for V.T.O.L. or, alternatively, aircraft size to do the mission will be appreciable.

The thrust/weight ratio required for S.T.O.L. in terms of take-off distance will be approximately as given in Section 3.0, except for the gain due to higher aspect ratio. It is unlikely that the technique of deflecting all the thrust during S.T.O.L. applicable to a small strike aircraft would be acceptable for a large freighter, and if a really short take-off, such as 500 ft. to 50 ft., is required, it would be better to design for V.T.O.L. from the start. If propulsion is by turbojets located on the wings, jet deflection applied to these engines is possible as illustrated in Fig. 6, reducing the required installed thrust in the lift engine pods. On the other hand the failure of a propulsion engine during V.T.O.L. must then be allowed for, and the lift engines in the pods on the failed engine side must be accelerated to maintain aircraft balance. This incurs an installed lift thrust penalty, so

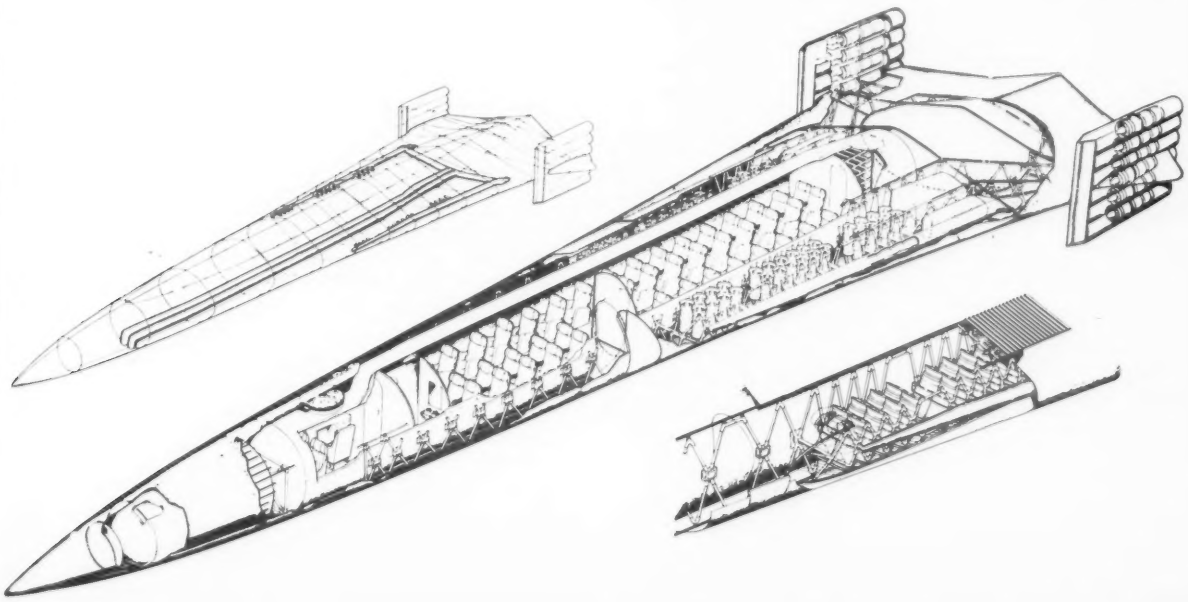


FIGURE 10. V.T.O.L. supersonic long-range civil air liner.

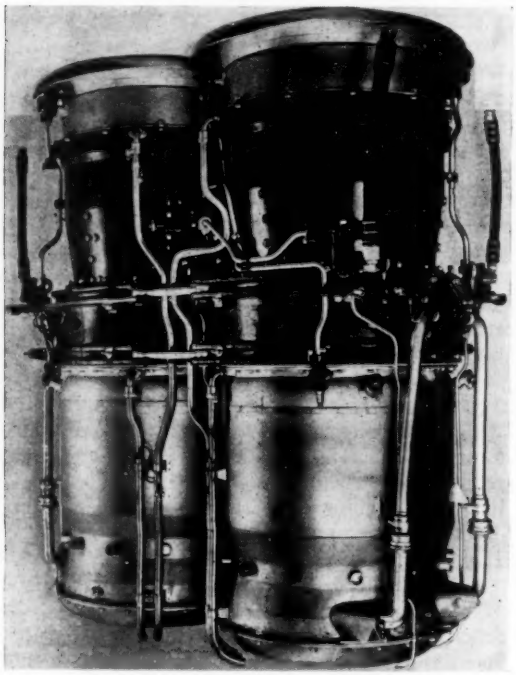


FIGURE 11. Pair of RB.108 lift engines.

that the full gain from propulsion engine thrust deflection is not obtained.

We have investigated the installed lift thrust/weight ratio required in a V.T.O.L. freight aircraft of the type illustrated in Fig. 5 to allow for various contingencies, including vertical acceleration, shift of centre of gravity, pitch and roll control, lift engine intake losses, inclination of lift thrust for acceleration and yaw control, and engine thrust decay for an ISA+20°C 2,000 ft. airfield, and find that a value of 1·4 to 1·45 is required referred to I.S.A., Sea Level conditions. The failure of two lift engines on one side is catered for by providing for an emergency thrust rating of 10 per cent which is never used unless an engine failure occurs. Hot and high airfields lead to severe penalties in installed thrust, but this does mean that for most take-offs the lift engines will be operating well within their maximum take-off rating, or that the aircraft can be over-loaded.

4. The Turbojet Lift Engine

The first turbojet to be designed specially as a lift engine was the RB.108 in 1954 and Type Tested in January 1958. There are four of these engines giving direct lift in the Short SC.1, and a pair is shown side by side in Fig. 11. The RB.108 has now completed a total of over 45,000 hours running on the bench and in flight. The engine, which incorporates swivelling mountings so that the engines can be tilted ±30° to the vertical, was designed to supply 10 per cent compressor delivery bleed air to aircraft control nozzles. The engines are roughly 20 in. diameter, and 42 in. long. Each engine gives 2,200 lb. thrust (with bleed), and 2,500 lb. (without bleed) for a weight of 285 lb., corresponding to a specific weight of 0·114 lb. wt./lb. thrust. This weight includes all the engine accessories mentioned, including the fuel system.

The RB.108 can be developed to over 3,000 lb. thrust and down to 0·10 lb./lb. specific weight, but to improve on these figures requires a complete redesign.

Pressure ratio is 5½, and the engine has an eight stage axial compressor and a two stage turbine. It is a three bearing engine with annular combustion chamber. The pressure ratio of 5½ was determined from considerations of combustion chamber loading, which at the time was regarded as very high. We now know that this loading can be increased.

With the knowledge and experience gained it is now possible to design a lighter, more simple and cheaper direct lift engine.

Engine designs were considered covering a range of pressure ratios and turbine entry temperatures using more modern compressor, turbine, combustion chamber and materials data, and it was concluded that a considerable reduction in specific weight could be achieved—specific weights not much more than half that of the present RB.108 were determined in the course of these studies. Also, a good deal of attention has been given to cheapening the lift engine, and it is my view that by simplification of design, and by using the latest materials and methods of manufacture the cost per unit thrust can be reduced to less than half that of an existing propulsion turbojet of the same thrust.

The variation of lift engine weight with engine size has also been considered to help the aircraft designer in his studies. We find that a lift engine giving 7,200 lb. thrust compared with one giving 3,600 lb. would be approximately 15 per cent greater in specific weight. This factor, together with that of short length, tends to favour lift engines smaller than 5,000 lb. thrust size.

A lift engine is essentially simple compared with a

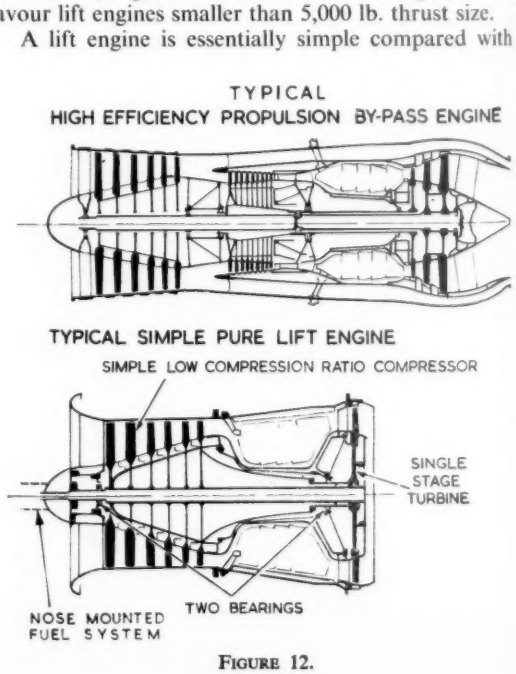


FIGURE 12.

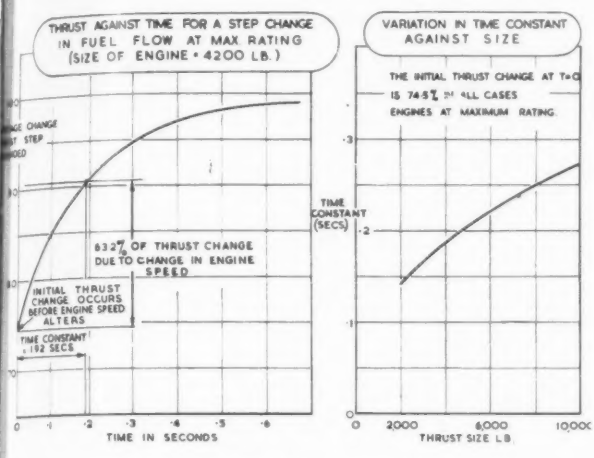

THRUST AGAINST TIME FOR A STEP CHANGE IN FUEL FLOW AT MAX RATING (SIZE OF ENGINE = 4200 LB.)
63.2% OF THRUST CHANGE DUE TO CHANGE IN ENGINE SPEED
INITIAL THRUST CHANGE OCCURS BEFORE ENGINE SPEED ALTERS
TIME CONSTANT .192 SECS
TIME IN SECONDS
VARIATION IN TIME CONSTANT AGAINST SIZE
THE INITIAL THRUST CHANGE AT T=0 IS 74·5% IN ALL CASES ENGINES AT MAXIMUM RATING.
TIME CONSTANT (SECS)
THRUST SIZE LB

FIGURE 13. Turbojet thrust response rates.

large single engine designed for both lift and propulsion. This is illustrated in Fig. 12 which shows the cross-sections of a large by-pass engine like the Conway, and a lift engine. The lift engine has roughly one quarter the number of components, does not have mechanical drives for auxiliaries, has a simple compressed air starting system direct onto the turbine, and a simple fuel system on the main shaft which has to operate only near sea-level. The lift engine requires 22 man hours to build and strip compared with 350 for a Conway. There is no more complexity in a group of four or six lift engines with systems than there is in a single Conway power plant pod on the Boeing 707.

4.1. LIFT ENGINE PERFORMANCE

Original optimisation studies were based on engine plus fuel weights, assuming three mins. lift engine operation at full power per sortie (take-off and landing). The Short SC.1 takes 30 secs. from wheels off the ground to wing-borne flight, so in future military aircraft it would seem that full lift engine power will be on for much less than three mins., possibly for one to two minutes only, the remaining time being at throttled back conditions. Lift engine fuel consumption is therefore of secondary importance to low engine weight.

The design lift thrust/aircraft take-off weight ratio will depend upon the aircraft configuration and operational environment. The factors are referred to in Section 3.4. The size or number of lift engines to meet the required take-off weight is determined by matching the maximum engine take-off rating to the hottest and highest operational conditions likely to be met. At this rating a lift engine would have an overhaul life of about 200 hrs., which corresponds very roughly to the 2,500 hrs. of, say, a Dart or fully developed civil Avon. Assuming one hour sorties, and that only 20 per cent of the take-offs will be at the full design rating at 100°F and 2,000 ft., the remaining 80 per cent of the take-offs being at I.S.A., Sea Level, and landing at 80 per cent take-off weight, this would result in a lift engine life of the order of 800 hours, or 16,000 airframe hours. These figures are given as a very approximate indication of lift engine operation. Intensive cyclic testing of the RB.108 engine is being done to establish a sound basis for the prediction of lift engine life in service.

In addition, it is possible to offer an emergency rating which would be used only in the event of one engine in a group failing. The life at emergency rating cannot yet be predicted with accuracy, and would be determined by normal service experience.

A lift engine must have good starting characteristics, a low idling speed, fast acceleration times and rapid thrust response to a stepped change in fuel flow. Most of these requirements are met by the RB.108 engine in the Short SC.1. The thrust response rate to throttle movement is approximately 0·10 sec., making aircraft height control by direct manual operation of collective throttle quite easy. Engine thrust response rate is particularly important if aircraft roll and pitch control is by differential throttling of lift engines, as it might be in the large freight aircraft illustrated in Figs. 5 and 6.

The curve on Fig. 13 shows how the thrust changes with time for a lift engine of 4,200 thrust. Combustion, which takes place in about 20 milliseconds, is responsible for 75 per cent of the stepped change. The right-hand diagram shows the effect of size on the time constant. The time constant is quite low, even for large engines. However, it should be noted that these times are increased when the engine is throttled back, which would be the case when landing after a mission with payload and fuel gone. This must be allowed for in any case where engine response rate is an important aircraft control factor.

5. Turbojet Lift Engine Installations

The installation of a group of lift engines with their control and systems is a new problem to the aircraft designer, and the ratio of the installed weight to the basic engine weight is the factor of chief concern to him. This ratio is of the order of 1·5 to 1·75 depending on the aircraft configuration, on whether differential throttling or bleed is required for aircraft control, and on what

TABLE III

INSTALLATION WEIGHT BREAKDOWN FOR JET LIFT ENGINE POD INSTALLATION

Sixteen basic lift engines including engine fuel system ...	100
Engine mountings	5·1
Lower doors (to close bay) and jacks	8·9
Upper doors (to close bay) and jacks	8·6
Intake cascades and jacks	9·0
Air starting system	6·6
Low pressure fuel system	2·8
Engine controls	2·8
Electrics	6·2
Fire protection	3·7
Fibre glass intake flare and straightening grid	5·8
Hydraulic systems (excluding jack)	4·5
Swivelling nozzles and actuators	10
Total =	74

$$\frac{\text{Ratio installed weight}}{\text{basic engine weight}} = 1{\cdot}74$$

A value of 1·5 should be possible for a fuselage installation

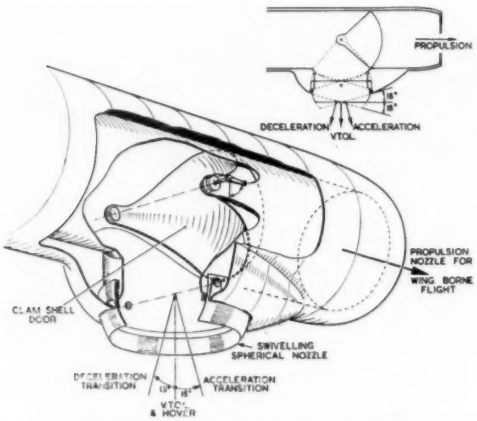


FIGURE 14. Two position jet deflector (with 30° range lift thrust angle).

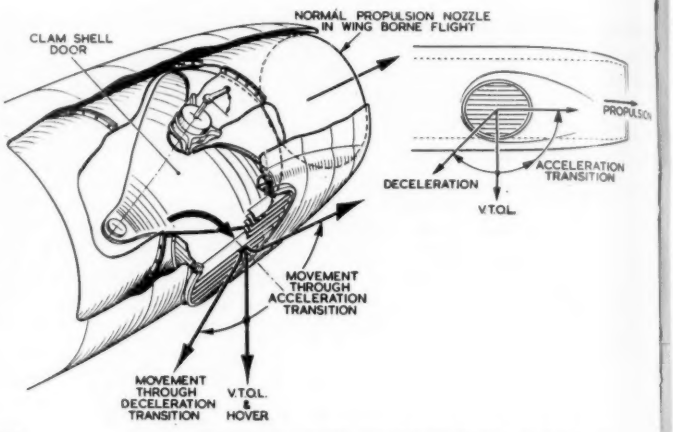


FIGURE 15. Fully variable angle thrust deflector.

range of jet deflection is required. It is of interest to set down all the items that are involved in a lift engine installation. Since this has been worked out in detail for a pod of lift engines as shown in Fig. 5, this case will be considered.

Each lift pod has 16 light weight lift engines of the type described in Section 4, the basic engine weight being here referred to as 100. Table III gives the estimated weight of all the installation features. The overall ratio of installed weight/basic engine weight is 1·74. For a fuselage installation of a smaller group of vertically mounted engines as in the delta configuration (Fig. 3) without jet deflection, this ratio is expected to lie between 1·5 and 1·6.

A similar ratio would apply to the lift engines in the swept wing configuration of Fig. 4. In this layout the two turbojet engines could be equipped with jet deflectors. These could be either of the two position type combined with a spherical nozzle to give a limited angle of jet deflection as shown in Fig. 14, or of the rotating cascade nozzle type shown in Fig. 15 giving progressive and fully variable thrust deflection for take-off, transition and landing. Both types of deflected nozzles are inoperative during cruise flight, the engine exhaust then passing through a normal propulsion nozzle. In this way the deflecting nozzle does not incur any penalty in cruise specific fuel consumption. Both deflectors incorporate thrust reverser eyelid doors of the type which are in service on civil Avon and Conway engines. For a 4,000 lb. thrust turbojet the thrust deflector shown in Fig. 14 would weigh approximately 100 lb., and the one in Fig. 15, 135 lb., both including actuators and control mechanism. These weights are equivalent to approximately 20 per cent of the basic engine weight, and when the loss of thrust in the deflected position is allowed for, 5 to 8 per cent of gross thrust, the increase in installed specific weight for these engines will approach 30 per cent. The installed volume of deflectors also incurs a weight penalty in the aircraft structure.

Lift engines which are installed with their axes vertical require a special design of intake, but fortunately a high pressure recovery in forward flight is not essential. To operate satisfactorily in both hover and transition the intake must accept two flow regimes, the first in hover with the air entering directly into the engines from above with negligible pressure loss, the second in transition with a variable flight/intake velocity ratio in which the air is turned through a right angle into the engine. Under these conditions, the total pressure into the engine must never fall below ambient static pressure, and the axial velocity distribution into the engine must be within the limits set by the behaviour of the lift engine compressor. Lift engine intake research has been a subject of special study, and we are satisfied that this problem can be solved in a new installation, as it was for the Short SC.1. Figs. 3 and 4 show a raised cascade type of intake combined with a straightening grid, which is one way of meeting the requirements.

After take-off and transition the intake and exhaust bays are closed off. For landing, the lift engines must be started in flight. This is done by opening the intake and exhaust doors, and raising the forward cascade to obtain ram pressure to "windmill" the engines to light up speed. A ram pressure recovery of 30 to 40 per cent at 200 knots would normally be adequate for this. As an added safeguard, the air normally tapped from the propulsion engine and fed to the lift engine starting air nozzles for the ground start, could also be used. It is also possible to start the lift engines by small hydraulic motors coupled directly to the rotors of each engine, using the aircraft hydraulic system. The starting cycle must be effected as quickly as possible to avoid wasting fuel. After light up, all engines are brought to idling speed, after which they are accelerated together up to the landing rating, which is a progressive process made as aircraft speed is progressively reduced below the stalling speed by throttling back the propulsion engine.

6. Turbofan Lift Engines

The thrust from a jet engine can be multiplied by two or three times by expanding the exhaust gases through an auxiliary turbine arranged to drive a high flow, low pressure fan. Using a light weight turbojet as the gas

producer, designs have been studied of several types of fan lift engines, the more important of which have been:

(*a*) Lift fan (or fans) driven by a multi-stage turbine in the hub of the fan. The turbine operates on the exhaust from the gas producer, which could be preheated. Assuming a multiple engine installation, after vertical take-off and during the transition, the turbojet exhausts are switched in sequence to propulsion nozzles, and the lift fans shut down and closed off during cruise.

(*b*) The gas producer drives an auxiliary compressor which supplies high pressure air to auxiliary combustion chambers. This air, after being preheated, enters the hub turbine of the lift fan (or fans). When the lift fans are shut down during cruise, the auxiliary compressor discharges through a propulsion nozzle, and this type of engine then becomes a by-pass engine with improved fuel consumption compared with (*a*). Ducting the lower temperature high pressure air from the auxiliary compressor to the lift fans is also more satisfactory than ducting the hot low pressure exhaust gas of system (*a*).

(*c*) The self contained turbofan engine which is installed in single units (Fig. 6) with separate propulsion engines of a type best suited to the aircraft duty, such as turboprops or by-pass engines.

The integrated power plants of (*a*) and (*b*) lead to complex installations and high installed weight penalties. An aircraft layout using system (*a*) with propulsion engines in wing pods, and lifting fans under the fuselage, had exhaust gas ducting alone amounting to 5 per cent of take-off weight. A layout using system (*b*) with a large number of small lift fans of shallow depth installed in the wing, required a wing area, when allowing for the ducting and preheat combustion chambers, equivalent to a wing loading of the order of 45/50 lb./ft.^{2} This was regarded as too low for efficient cruising flight for the project under consideration. In addition, the lift fans must be shut down and closed off during transition and cruise. This leads to a complicated fan intake and exhaust slat system and control procedure during transition, quite apart from the mechanical difficulties and aerodynamic losses involved.

For these and other reasons the self contained turbofan engine (*c*) is favoured for any immediate development, and this is why the pod installation of Figs. 5 and 6 is considered to be the most practical installation of lift fan engines at this time.

6.1. THE SELF-CONTAINED TURBOFAN LIFT ENGINE

In this engine the fan and its turbine are designed as an integral part of a light weight gas producer which can be as light in construction as the turbojet lift engine referred to in Section 4, since it only has to operate during take-off and landing. Three possible ways of doing this are:

(*a*) The fan and its hub turbine can be designed into the exhaust system of the gas producer, and run on a separate shaft.

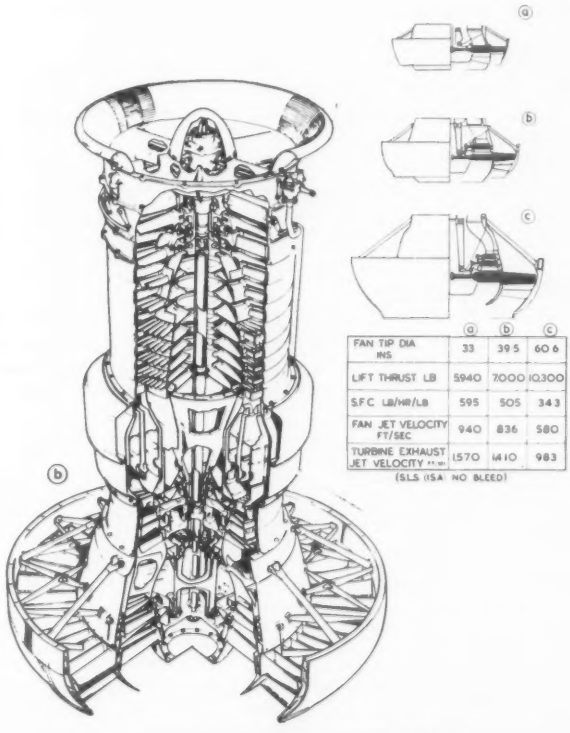
(*b*) The fan may be at the front and driven from an auxiliary turbine at the rear of the engine through a separate shaft. In this case the fan lift engine becomes a two-shaft high by-pass ratio engine of similar general layout to the Conway.

(*c*) The fan can be gear driven from the gas producer, in which case it can be located at the front of the engine.

Each of these schemes has its particular merits. The first two have good starting and acceleration from low speed characteristics compared with the third which, being in effect a single shaft engine, may have to be provided with variable geometry fan stator blading. The first has the obvious advantage that it can be developed directly from the light weight turbojet lift engine by the addition of the fan unit. For given gas producer dimensions, the fan size can be varied to give a fairly wide range of thrust to meet varied aircraft requirements.

When these fan-lift engine design studies were started three years ago it was expected that the specific weight of fan-lift engines based on lift thrust would be appreciably lower than for the turbojet lift engine. This has not been realised. The specific weight of a fan engine would appear to be about 10 per cent higher than that of the lightest turbojet lift engine giving the same thrust. Further, the present conclusion is that in spite of the lower fuel consumption of the fan engine, the lift fan engine plus fuel plus installation weight, allowing 3 minutes at full power for take-off and landing, will be greater than for a pure jet lift engine installation having the same total lift thrust.

The main reason, and an important reason for continuing to work on the fan-lift engine, is that its lower



	a	b	c
FAN TIP DIA INS	33	39·5	60·6
LIFT THRUST LB	5940	7000	10,300
S.F.C. LB/HR/LB	595	505	343
FAN JET VELOCITY FT/SEC	940	836	580
TURBINE EXHAUST JET VELOCITY FT/SEC	1570	1410	983

(S.L.S. ISA NO BLEED)

FIGURE 16. Alternative lift turbo fans.

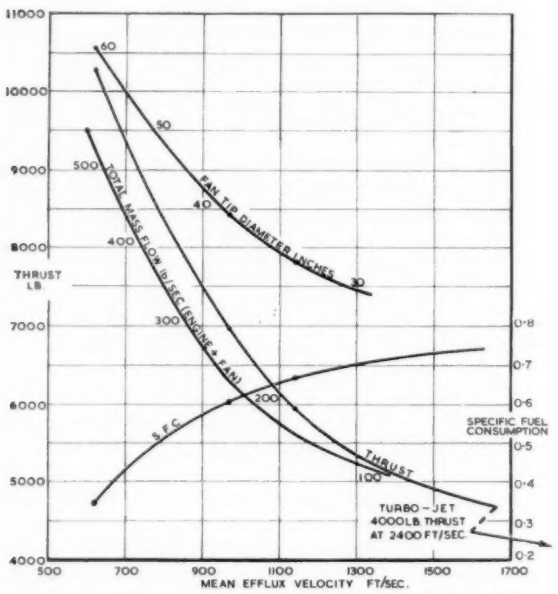


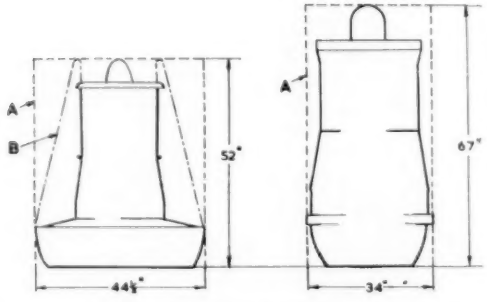
FIGURE 17. Direct gas driven turbofan lift engines. Effect of jet efflux velocity on thrust, S.F.C. and fan tip diameter based on 4,000 lb. thrust turbo-jet.

jet velocity offers the best solution at the present time to reducing the noise of a V.T.O.L. aircraft.

Some of the performance, weight and noise characteristics of the rear fan type of lift engine are now considered.

6.2. PERFORMANCE CHARACTERISTICS OF THE REAR FAN LIFT ENGINE

A gas producer which as a jet engine would give 4,000 lb. thrust is shown in perspective section with a turbo-fan designed into the exhaust system in Fig. 16. The thrust of this engine is 7,000 lb., hence the fan produces a thrust augmentation ratio of 1·75. In the inset diagrams of Fig. 16 two other fan sizes are shown, one smaller with a single stage fan turbine, and one larger with a three stage turbine. The thrust that it is



	REAR FAN ENGINE	PURE JET ENGINE
CYLINDER PROFILE AREA A	2300 SQ. INS.	2300 SQ. INS.
CYLINDER VOLUME	80,000 CU. INS.	60,000 CU. INS.
PROFILE AREA SIDE B INTAKE CASE	1,900 SQ. INS.	—

FIGURE 18. Comparison of turbofan and pure jet lift engines. Thrust = 7,500 lb. each.

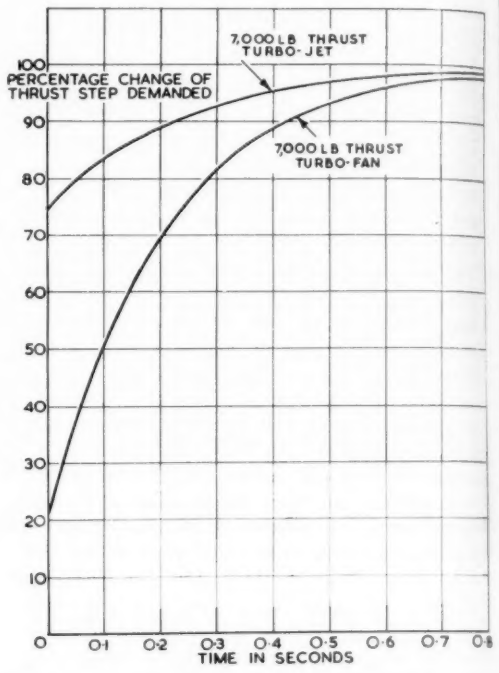


FIGURE 19. Comparison of the thrust response curves of a lift turbofan and a pure jet at the same lift thrust of 7,000 lb

possible to obtain with this basic arrangement covers the range from 6,000 to 10,000 lb., and the table in Fig. 1 gives the specific fuel consumption and jet velocities in each case. The specific weights of the two smaller turbofan engines are nearly the same and 10 per cent greater than the basic gas producer as a jet lift engine but the largest fan engine shown is approximately 20 per cent greater. We find that the specific weight rises sharply above a thrust augmentation of $2\frac{1}{2}$.

The relationship between lift thrust, SFC, fan diameter and mass flow with the mean efflux velocity is shown in Fig. 17. It will be seen that whereas the thrust augmentation of the largest fan is $2\frac{1}{2}$, the total mass flow (gas producer plus fan) has increased by approximately 10 times. It is this large mass flow which makes the low efflux velocity fan engine so difficult to install in the aircraft.

It is interesting to compare the size and bulk of a fan lift engine giving 7,500 lb. thrust with a turbojet lift engine of the same thrust. (*See* Fig. 18 which includes a table of comparative data). The fan engine is short in relation to its diameter, but its installed volume is larger, causing installation weight penalties. In a pod installation the fan air could be designed to enter from the top, as indicated, or from the sides.

In Fig. 19 the thrust response rate of a turbofan is compared with that of the turbojet, both at 7,000 lb. thrust size. The much inferior lead-lag ratio of the turbofan is evident, the time required for the turbofan to reach 90 per cent of the thrust step demanded being approximately twice that taken by the turbojet. This could be important in deciding whether differential throttling of

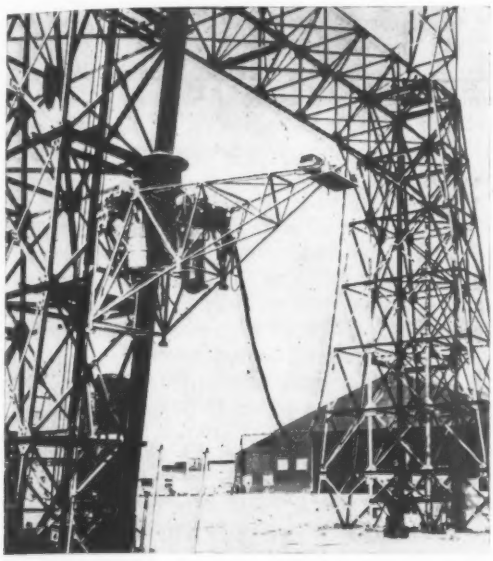


FIGURE 20. RB.108 engine on height control trolley.

engines for aircraft control is a practical proposition with turbofans. Clearly, this characteristic could set a limit to the design value of the thrust augmentation ratio. Variable geometry fan blading could be used to increase the response rate, but this kind of complication should be avoided on a lift engine. The height control trolley shown in Fig. 20 has been used to investigate engine thrust response rate on the ability of a pilot to operate the engine throttles manually when controlling aircraft height, especially on landing. This apparatus is also being

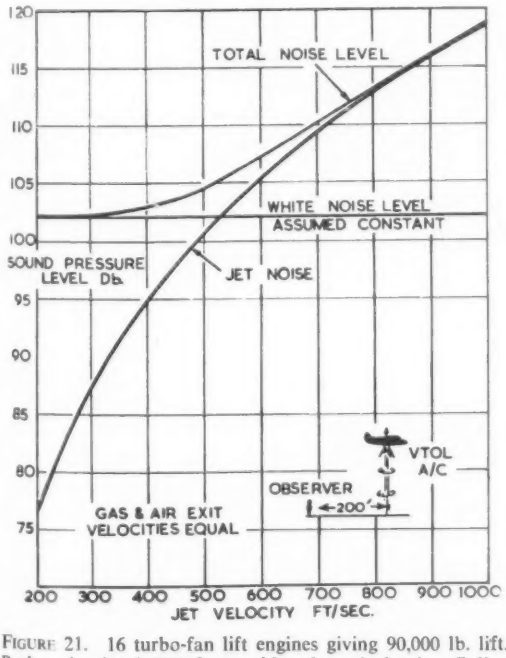


FIGURE 21. 16 turbo-fan lift engines giving 90,000 lb. lift. Peak noise level 200 ft. to side of vertical take-off line plotted against efflux velocity.

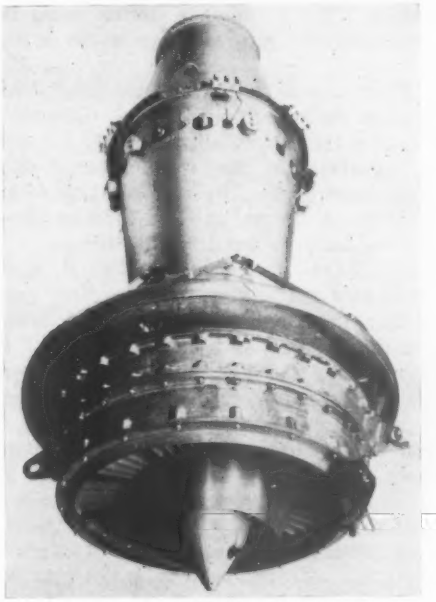


FIGURE 22. Turbo-fan research unit.

used to develop a completely automatic throttle control operated from the signals of a radio altimeter. An RB.108 is used in these experiments.

To reduce the jet noise of a large V.T.O.L. transport or freight aircraft to an acceptable level it was thought that the mean turbofan engine efflux velocity would have to be reduced to a value of the order of 600 ft./sec. This, as will be seen from Fig. 17, leads to a very large diameter, high flow fan. Such a large fan will generate a great deal of noise within its own blading, and would be more objectionable than jet noise. The problem is illustrated in Fig. 21, which was an early attempt to calculate the fan blade noise and jet noise for 16 turbofan engines giving a total thrust of 90,000 lb. The fan blade or "white" noise is shown constant as jet velocity is reduced, but this is probably optimistic. To investigate turbofan noise the research unit shown in Fig. 22 has been constructed. This is a single stage fan with a four-stage hub turbine which has completed performance tests, and is now undergoing noise tests. The noise emanating from the front and rear of the fan unit are being separately assessed.

7. Conclusions

1. The Short SC.1 research aircraft with a composite power plant has demonstrated the feasibility of V.T.O.L. using special light weight turbojet lift engines to support the aircraft and supply the air for pitch and roll control jets. Propulsion is by a separate turbojet and, when wing-borne speed has been reached, the lift engines are shut down. They are restarted in flight for the vertical landing.

2. Compared with the RB.108 lift engines in the Short SC.1, it is now possible to approximately halve the specific weight. If these engines are used in conjunction with an efficient by-pass propulsion engine, a

useful small V.T.O.L. military aircraft could be built following closely the general design layout of the Short SC.1.

3. Alternative aircraft layouts are possible in which the thrust of the propulsion engine is deflected during V.T.O.L. to reduce the installed thrust of the special lift engines. However, the gains from deflecting propulsive thrust are largely offset by the installed weight and volume of the deflectors, and the need to avoid large aircraft trim changes when deflecting thrust.

4. If S.T.O.L. is defined as 500 ft. horizontal distance to 50 ft. height, the propulsive thrust required is greater than the aircraft take-off weight, even if an optimum thrust deflection technique at unstick is used. The aircraft flight speed at the screen would probably not be high enough to ensure adequate control stability, and auxiliary control means using reaction nozzles supplied by the engine would almost certainly be required.

5. The S.T.O.L. low level subsonic strike aircraft with deflected thrust has a better range capability with a composite power plant consisting of light weight booster engines for take-off combined with an efficient propulsion engine matched to the cruise thrust requirement, compared with a single engine configuration. Supersonic capability can be obtained by the application of reheat to the propulsion engine (or engines) in the composite power plant.

6. If full advantage is taken of designing the V.T.O.L. aircraft with low aspect ratio and a wing not compromised for runway take-off and landing requirements, it would appear that appreciable saving in structure weight is possible. It is concluded that a V.T.O.L. low level subsonic strike aircraft need be only a little heavier than the S.T.O.L. aircraft with the deflected thrust composite power plant for the same operational range, but this requires verification by the aircraft designer.

7. The most practical solution at the present time to the design of a large V.T.O.L. transport or freight aircraft seems to be one in which the lifting engines are installed in two wing pods. Such an arrangement offers little scope for the reduction of structure weight, and V.T.O.L. capability incurs severe payload and range penalties. On the other hand such an aircraft would be useful for gaining operational experience, and would enable the multiple lift engine power plant and systems to be developed in readiness for the next stage in aircraft design.

8. Power plants in large V.T.O.L. aircraft in which gas or compressed air is ducted from engines to lift fans suffer severe installed weight penalties because of the length and complexity of ducting, valves, and control system. It would seem unlikely that such power plants will ever be a practical proposition when applied to aircraft of conventional configuration.

9. While the small turbojet lift engine of 3,000 to 5,000 lb. thrust would appear to be the most suitable for the small V.T.O.L. military aircraft, the self-contained turbofan lift engine of 8,000 to 12,000 lb. thrust would seem to be the present choice for the large freight aircraft, mainly to reduce noise. The large fan lift engine may have limitations as regards aircraft control because of lower thrust response rate, and the relatively large thrust penalty incurred if designed to supply high pressure control jets.

10. A great deal more effort is required by aircraft designers and Research Establishments to evolve new V.T.O.L. aircraft configurations to use the light weight turbine engines which will be developed.

Acknowledgment

The author gratefully acknowledges the valuable assistance given by the Aircraft Performance and Engine Installation Design sections, and other associates in the preparation of this paper. He also thanks the Directors of Rolls-Royce Ltd. for permission to publish the paper.

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Some Current Problems Facing the Aircraft Designer*

BY

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(Chief Engineer, Advanced Projects Group, Hawker Siddeley Aviation Ltd.)

Foreword

While the subject of this paper is concerned with problems somewhat outside the scope of those which existed in the days of the late Roy Chadwick, nothing absorbed Chadwick's interest more than a seemingly intangible aircraft problem, and I am sure that had he been alive today he would have been deeply involved in the search for solutions to them.

He was without doubt a man of great talent, with an intuitive flair for design, and I join the many members of his staff who deem it a great privilege to have been associated with him for many years; and am honoured to have been asked to present this Memorial Lecture.

1. Introduction

There has never been a more challenging period in the history of aeronautical endeavour than the present.

Since the Second World War the rapid growth of knowledge on supersonics derived from the military flying of supersonic fighters and bombers, and the more recent emphasis on V/STOL designs, of which more than 20 have now flown, has opened up tremendous possibilities in both the military and the civil fields.

It would be a brave man, and indeed a reckless one, who would attempt to establish the limits of progress that might be made in Aviation in the next decade or so and while I have highlighted in this paper one or two problems that presently do not appear to have ready solutions, I am convinced that their solution is merely a matter of time and effort and hope that the following free discussion of them may help to shorten that time.

It is obviously not possible to cover adequately more than one or two outstanding problems in a relatively short paper and I have therefore concentrated mainly on the problems facing the designers of high speed civil aircraft in the areas of:

1. AIRCRAFT NOISE, including:
   (*a*) The Increase in Aircraft Ground Noise.
   (*b*) The Sonic Boom.

and 2. THE INCREASING RATIO OF HIGH TO LOW SPEED

These problems can affect the design solutions for high speed civil aircraft to an extent which might not have been generally realised. The fact that this paper is more or less a problem statement makes it difficult to advocate specific cures for the problems stated since they would cease to exist if an easy solution were available. However, I have attempted to show some of the factors involved in considering these problems in the early design stages and to suggest possible avenues of research, to help in resolving them.

*This paper formed the basis of the Sixth Chadwick Memorial Lecture, given to the Manchester Branch of the Royal Aeronautical Society on 15th March 1961.

2. Aircraft Noises

The Supersonic Transport, which we can expect to be in operation by about 1970, will emit a variety of noises which cannot be ignored and which are difficult to reduce by application of current knowledge on the subject.

On the ground and in the immediate vicinity of the airport the main source of noise will be the propulsion system.

During the cruise the main source of noise reaching the ground will be from the "Sonic Boom."

Much has been written individually on these subjects but I will attempt to show the combined effect of these noises on the operating aspects of future Supersonic Transports, since they may well have a profound effect on the size, configuration and general operation of this type of aircraft. The latest data available on Sonic Booms, for instance, is likely to call for a reassessment of aircraft size and cruising techniques over land areas.

2.1. AIRCRAFT GROUND NOISE

The noises caused by aircraft taking off and landing have been steadily increasing in recent years and the advent of the large passenger jets has brought about a marked increase in noise levels around the airports.

In view of positive public reaction to this increase in noise it is now considered in responsible circles that the present noise levels caused by the take-off and landing of large jet aircraft, such as the Boeing 707 and Douglas DC-8, are about the maximum that will be tolerated in the future and, in fact, there is a strong representation from various bodies to bring about a reduction in noise on a long term basis.

Noise regulations have now been put into operation both at Idlewild and London Airports, with noise measuring equipment stationed at a point immediately under the flight path of the aircraft. At least one American airline has been cautioned for exceeding the limits imposed and strict disciplinary measures are likely to be imposed for future violations.

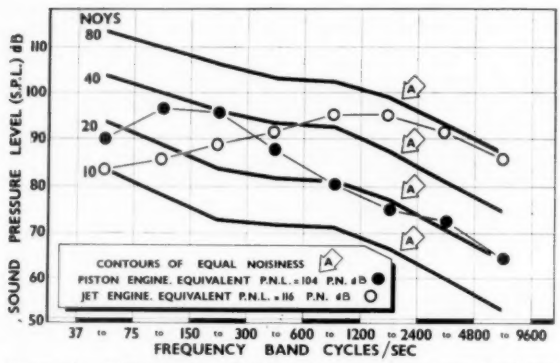

FIGURE 1. The response of the ear to sound pressure level and frequency.

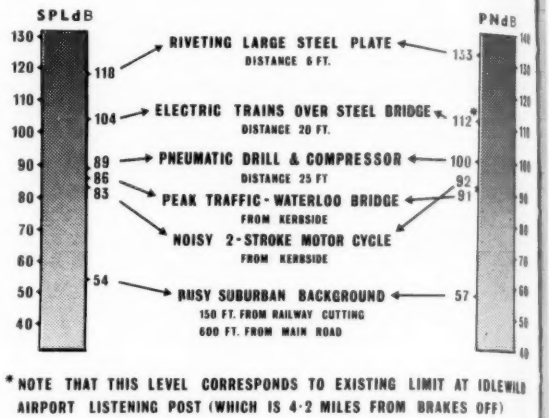

FIGURE 2. Noise levels associated with familiar sounds.

2.2. NOISE MEASUREMENT

While noise is a very real and powerful thing it is generally accepted that the annoyance caused by aircraft noise on the ground cannot be established in scientific units or absolute terms. Individuals exhibit different reactions to the same noise and it is only possible to establish generally acceptable noise levels based on more or less mass reaction to that particular kind of noise.

The average human ear can detect cyclic pressure fluctuations in a frequency band of from roughly 30 to 15,000 cycles per second and responds approximately on a logarithmic basis to the mean square of the fluctuating sound pressure. However, it is now well known that two sounds at the same sound pressure level (S.P.L.), but of different frequency, will have different annoyance factors since the human ear is very sensitive to higher frequency levels.

Kryter[1] has attempted to correlate the human response to frequency at various sound pressure levels by the establishment of an "equal annoyance" datum which is designated as the NOY. Fig. 1 shows how this datum varies with frequency; a typical jet and a typical piston engined aircraft are shown and these give an indication of the effect of frequency on peak noise levels. It can be seen that while the peak sound pressure levels are comparable, they occur at different frequencies and the jet aircraft would have a peak NOYS value of almost twice that of the aircraft with piston engines.

Since the human ear is exposed to the various audible frequencies at the same time, a statistical research into listener reactions has been made which allows varying emphasis to be placed on S.P.L. readings in each octave band.

The American Company of Bolt, Beranek and Newman have evolved a method which weights the sound pressure levels in each frequency band by a frequency dependent "annoyance factor"[2]. the sum of these contributions to annoyance at the different frequencies is expressed as a "total noisiness" or "perceived noise level" (P.N.L.). In the example shown on Fig. 1 the resulting P.N.L. for the particular jet aircraft shown would be about 116 PNdB. while that for the piston-engined aircraft would be about 104 PNdB. In order that these noise levels can be understood more closely, Fig. 2 shows the equivalent noise levels associated with more familiar sounds[3].

It should be noted that the establishment of P.N.L. as a balanced subjective noise measurement is not proving to be as generally acceptable as had at first been assumed. For instance, two engines designed by different manufacturers, when tested, resulted in subjective reactions opposite to those indicated by P.N.L. measurements. The calculation of P.N.L. for a paper engine is complicated and involves the examination of the complete noise spectrum for every throttle setting.

Dissatisfaction with the "perceived noise" scale is indicated by recent noise level quotations in PHONS, which are a measure of loudness rather than annoyance, but which also take into account frequency effects.

There is no doubt that present methods of assessment of the annoyance level of a particular engine leave much to be desired.

2.3. NOISE SOURCES

The jet engine has two main sources of noise, the jet efflux noise, caused by fluctuating shear flow in the turbulent mixing of the high velocity jet and the surrounding relatively stationary air, and the noise from the compressor and mechanisms, which is more difficult to calculate or analyse than the jet efflux noise. Combustion noise is comparatively insignificant in a high-velocity jet engine.

Lighthill[4] has shown that the noise pressure amplitude varies as d^2v^8, where d is a characteristic dimension such as the jet diameter and v is the jet velocity, whereas thrust varies as d^2v^2. It is therefore possible to considerably reduce the noise emitted from the jet for a given thrust by increasing the diameter of the jet, which is achieved in the by-pass or ducted fan engine. However, as the by-pass ratio is increased the compressor, which is becoming more highly loaded, produces a higher noise level from the intake.

As a general rule it can be assumed that, for a given thrust and jet pipe temperature, a 3 per cent increase in jet velocity gives approximately 1 dB increase in sound pressure level. If the increased thrust can be achieved by larger diameter engines with comparable jet velocity, the

noise levels will not increase appreciably for a relatively small increase in thrust. If the higher thrust is obtained by increasing velocity the noise is likely to increase considerably.

Figure 3 indicates noise levels for both intake and exhaust on a typical jet engine of around 10,000 lb. thrust. It can be seen that for a straight jet engine with a jet velocity of 2,000 ft. per sec. the unshrouded intake noise is approximately 18 dB less than the exhaust noise measured in S.P.L. For a by-pass or ducted fan engine with a by-pass ratio of approximately 1·7 and a final jet velocity of 1,200 f.p.s., the exhaust noise is reduced by between 15 and 20 dB, while the intake noise is increased by between 8 and 10 dB; this means that the intake noise is now some 10 dB higher than the exhaust noise and, since it is of higher frequency, would be more annoying. Intake shrouding would reduce the noise by a small amount but would still leave the intake noise at a higher value than that of the exhaust.

Figure 4 illustrates the estimated effect of using a by-pass engine on the perceived noise experienced by an observer standing at various distances from the noise source. While the decrease in exhaust noise is substantial with the by-pass engine, it can be seen that the increase in intake noise is also quite marked.

Figure 5 shows the noise level, for both the turbojet and by-pass engine, experienced by an observer directly under the take-off path of a contemporary aircraft with a climb angle of 15° and also the noise level during landing with an approach angle of 3°. This again indicates that although the by-pass engine considerably reduces the take-off noise, it has a slightly higher noise level than the turbojet during landing. This is, of course, a function of the power setting required during landing and would vary slightly for different aircraft.

2.4. PRESENT OVERALL NOISE LEVELS

Figure 6 shows the perceived noise levels and time of exposure for an observer standing directly under the flight path of a Boeing 707/120, measured at London Airport[5]. The noise level at take-off was measured at a point 2·5 miles from "brakes off" and the landing noise was measured at 3,000 ft. before the threshold of the runway. It can be seen that the highest value of perceived

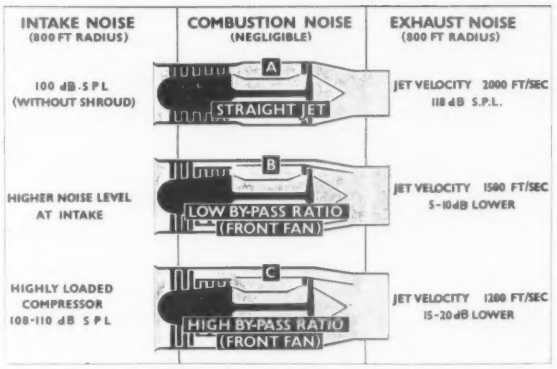

FIGURE 3. Main source of noise generated by typical jet engines of 10,000 lb. thrust.

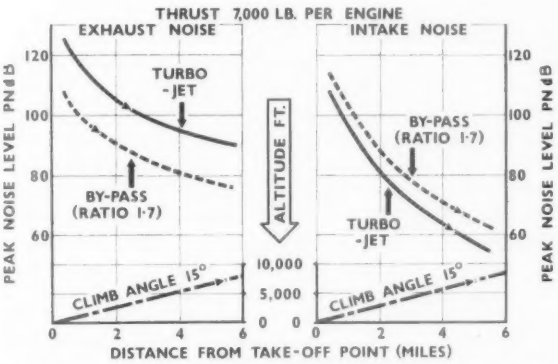

FIGURE 4. Noise under flight path for turbojet and by-pass. Four-engined aircraft during take-off.

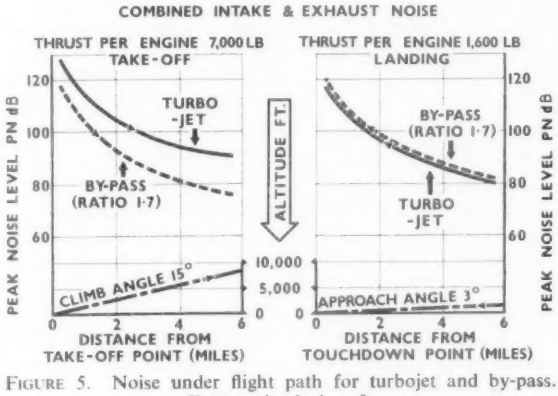

FIGURE 5. Noise under flight path for turbojet and by-pass. Four-engined aircraft.

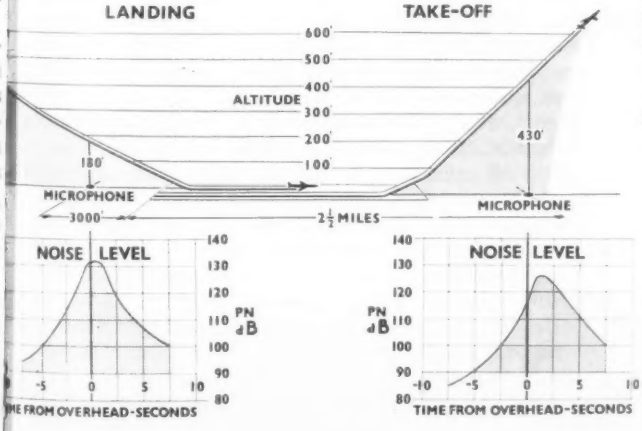

FIGURE 6 (*left*). Noise under flight path during take-off and landing of Boeing 707/120 at London Airport.

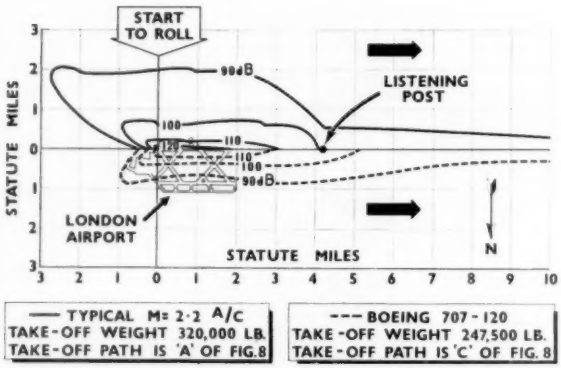

FIGURE 7. Sound pressure level contours at take-off.

noise is reached during landing. The Boeing 707/120 uses suppressors of Type F (*see* Fig. 10).

2.5. EXPECTED GROUND NOISE LEVELS ON FIRST GENERATION SUPERSONIC TRANSPORTS

The propulsive power required for a Supersonic Transport is of necessity considerably higher than that required for the current range of intercontinental jet aircraft, such as the Boeing 707 and Douglas DC-8, and the thrust required for a 100 passenger $M=2\cdot2$ Trans-Atlantic transport weighing around 320,000 lb. would be in the order of 120,000 lb. S.L.S. The thrust required for a similar $M=3$ Transport, weighing approximately 350,000 lb., would be in the order of 150,000 lb. S.L.S. These values compare with the present Boeing 707/120 thrust of approximately 54,000 lb.

Figure 7 gives a comparison between the sound pressure levels at London Airport likely to be experienced from the present Boeing 707[6] and the $M=2\cdot2$ Supersonic Transport. It can be seen that the width of saturation with more than 90 SPL dB is considerably greater for the Supersonic Transport although, since it has better rate of climb-away, the longitudinal cut-off at 100 dB is earlier than with the present jet.

2.6. OPERATING TECHNIQUES

There are special techniques which can be employed to reduce the noise levels from the Supersonic Transport at the official listening point, which is approximately 4·2 miles from the "brakes-off" end of the runway at London Airport. Fig. 8 demonstrates two techniques for take-off and the present "minimum noise" method for the Boeing 707/120 is shown for comparison.

Technique (*A*) involves the aircraft doing a normal take-off at a speed of about 170 knots at the 50 ft. point. A normal climb then takes place and when the aircraft has reached an altitude of approximately 1,600 ft. it is then levelled off and accelerated to 220 knots at the listening point. The engines are then throttled back for passing over the listening point and the speed kept reasonably constant while the aircraft climbs to an altitude of around 3,000 ft. at a point 10 miles from start. It was estimated that, using this technique, the sound pressure level over the listening point would be around 97 SPL dB, or 110 PN dB.

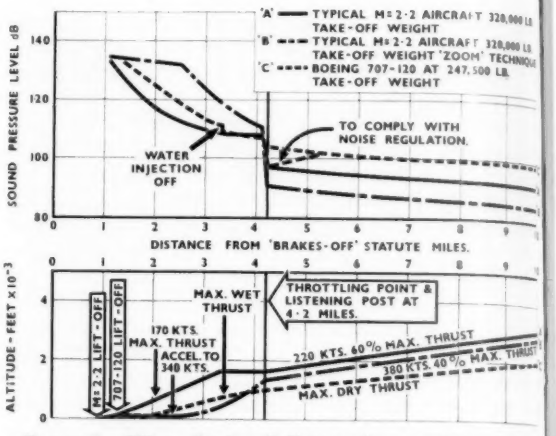
'A' TYPICAL M= 2·2 AIRCRAFT 320,000 LB TAKE-OFF WEIGHT
'B' TYPICAL M= 2·2 AIRCRAFT 320,000 LB TAKE-OFF WEIGHT 'ZOOM' TECHNIQUE
'C' BOEING 707-120 AT 247,500 LB. TAKE-OFF WEIGHT
SOUND PRESSURE LEVEL dB
WATER INJECTION OFF
TO COMPLY WITH NOISE REGULATION.
DISTANCE FROM 'BRAKES-OFF' STATUTE MILES.
ALTITUDE - FEET x10⁻³
M=2·2 LIFT-OFF
707-120 LIFT-OFF
MAX. WET THRUST
THROTTLING POINT & LISTENING POST AT 4·2 MILES.
170 KTS. MAX. THRUST ACCEL. TO 340 KTS.
220 KTS. 60% MAX. THRUST
380 KTS. 40% MAX. THRUST
MAX. DRY THRUST

FIGURE 8. Effect of take-off flight path on noise under trac

A different technique (*B*) is also shown in Fig. 8 and basically as follows:

The aircraft is accelerated to as high a speed a possible after unstick and the aircraft continues t accelerate until just before the listening point, by whic time it has reached a speed of approximately 380 knots The engines are then throttled back and the aircraf climbs at 40 per cent power, taking advantage of th speed gained during the low level acceleration. Thi engines are opened up again at some predetermine point, when the aircraft is at an altitude where the nois will not be objectionable, and the aircraft continues it climb.

This technique reduces the sound pressure level jus before the listening point to approximately 91 SPL dB o 104 PN dB. In both cases throttling back reduces th sound pressure levels to the accepted limit, which is i the region of 97 SPL dB or 110 PN dB.

While these techniques would reduce noise levels at a somewhat arbitrary official listening point and (*B*), in particular, reduces the sound pressure level over a relatively large area after the listening point, it is not expected that this method of noise reduction would b very palatable to the operators, since (*B*) involves holding down the aircraft until it has reached a much higher transit speed to the listening point and produces considerably higher noise levels in the immediate vicinity o the airport. It is also questionable whether rapid acceleration of the aircraft below 1,500 ft. would b acceptable with regard to safety in the flight contro pattern.

Any increase in aircraft gross weight could have a marked effect on these attempts to alleviate noise b take-off techniques since it would increase the amount of thrust required for take-off or, reduce the height-speed combination at any given point beyond the runway

While careful application of such techniques might bring the 320,000 lb. $M=2\cdot2$ Transport within acceptable noise limits on the ground, it will not necessarily alleviate the noise problems encountered with a faster or heavier aircraft in the future. It is also difficult to calculate the actual noise levels which are likely to be acceptable on new and, as yet, paper engines since the

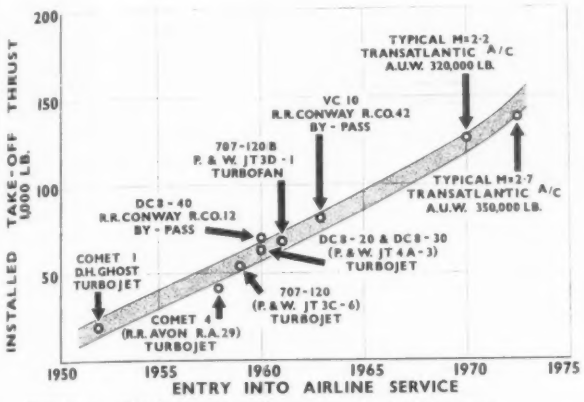

FIGURE 9. The increasing take-off thrust of civil aircraft.

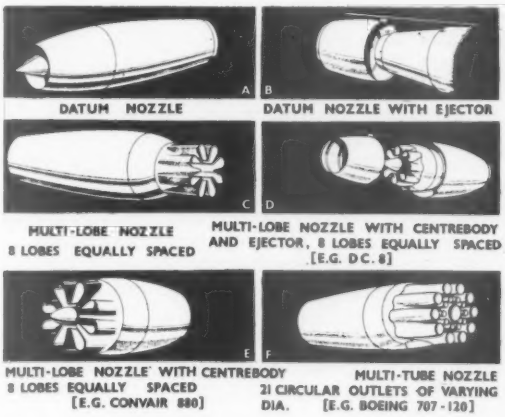
A
DATUM NOZZLE
B
DATUM NOZZLE WITH EJECTOR
C
MULTI-LOBE NOZZLE 8 LOBES EQUALLY SPACED
D
MULTI-LOBE NOZZLE WITH CENTREBODY AND EJECTOR, 8 LOBES EQUALLY SPACED [E.G. DC. 8]
E
MULTI-LOBE NOZZLE WITH CENTREBODY 8 LOBES EQUALLY SPACED [E.G. CONVAIR 880]
F
MULTI-TUBE NOZZLE 21 CIRCULAR OUTLETS OF VARYING DIA. [E.G. BOEING 707-120]

FIGURE 10. Typical jet noise suppressor configurations.

shape of the frequency spectrum is not readily amenable to calculation and small variation in the upper frequency bands have a considerable effect on perceived noise levels.

Actual noise levels reaching the ground are also affected by Doppler change due to the aircraft motion relative to an observer on the ground. Atmospheric attenuation of perceived noise levels is also marked. Suppressor effectiveness also tends to reduce sharply as the thrust is reduced during the throttling procedure.

2.7. POSSIBLE INCREASE IN GROUND NOISE PROBLEMS IN THE FUTURE

Figure 9 gives an estimate of the projected increase in total installed thrust that is likely to be required on future large aircraft[7]. If we assume, as previously suggested, that noise levels will not be allowed to increase and that, in fact, a reduction is required for the next generation of aircraft, we are faced with the problems of attempting to obtain lower than current noise levels for aircraft which have a total installed thrust of two to three times current values.

This problem obviously requires a technical breakthrough in the reduction of propulsive noise for the second generation of Supersonic Transports and a breakthrough might even be required for the larger first generation supersonic aircraft.

Special flight planning will go part of the way and by-pass engines will alleviate the problem to some extent, but there are limits to these techniques; for instance, the by-pass ratio must be consistent with obtaining adequate thrust at supersonic speed, which may require some burning in the by-pass stream, and the engine diameter must be consistent with the lowest possible weight and drag per lb. of thrust. The aft fan configuration might reduce intake noise levels on the ground considerably and with after-burning in the fan stream it might be possible to achieve acceptable thrust levels during transonic acceleration and during cruise. (It should also be mentioned that specific thrust measured in lb. of thrust per lb. of air per sec. decreases with increase in by-pass ratio).

The contribution of the intake to the total noise may well be a major problem as compressors become more highly loaded with high by-pass ratio engines and, as mentioned earlier, it is difficult to calculate accurately the noise emitted by a highly loaded compressor, especially during semi-stalled conditions. It may, however, prove easier to silence the intake noise than that of the exhaust; for instance, it is possible to line the intake duct with acoustic lagging and the installation of a sonic intake throat could prevent much of the sound being emitted forward. Some noise would be released through the boundary layer but this might be within acceptable limits. There is one alleviating factor with regard to intake noise on Supersonic Transports. The intake will be of variable geometry and it should not be difficult to provide sonic throat conditions.

However, it must obviously be to the engine manufacturers that we look for a real solution to the main problems of engine noise and, while much work has already been done on noise suppression by the engine companies in the past, if we are not to be severely limited in our future designs the growing problem of noise suppression requires a much greater effort in the immediate future.

2.8. PRESENT STATE OF THE ART ON JET EFFLUX SUPPRESSORS

It would be impossible to cover all the work that has been done on jet efflux suppressors in a short section of this paper, but the suppression of engine noise so far has mainly taken the form of jet nozzle attachments. These attachments increase the mixing area and hence reduce the fluctuating velocities in the highly turbulent mixing region of the jet and the surrounding air; this in turn reduces the noise output. Deflectors have also been installed at the appropriate positions on the airfields, but this only reduces the local noise when the aircraft is stationary.

Figure 10 shows a few of the suppressors which have been tested, some of which are at present used on the large jet transports. A considerably larger range of suppressors has been tested as a result of extensive work on this subject by the engine manufacturers, notably Rolls-Royce and Pratt and Whitney, and the aircraft manufacturers of the large jets, mainly Boeing and Douglas; although a number of other organisations

have also done considerable work on this. While insufficient data is available to enable a comparative assessment of the ground noise attenuation using these suppressors, it is believed that the maximum reduction in noise achieved up to the present time is about 6 PN dB at 400 ft. radius at sea level.

It is obviously important in suppressor design to take account of the effects of the suppressor under cruise conditions and to minimise the thrust loss and increase in drag and the resulting increase in aircraft weight. It is also important to ensure that the device is compatible with the thrust reversing mechanism if this is fitted.

One of the factors resulting from the use of a jet nozzle suppressor is the large change in the frequency spectra. Fig. 11 shows the typical results obtained with a Boeing 707 with JT3C engines during a 400 ft. altitude fly-over with engines at full wet power[8]. Comparisons are shown between the sound frequency spectra for engines with (*a*) no suppressors, (*b*) 9 tube suppressors, and (*c*) 21 tube suppressors. It can be seen that while the 21 tube suppressor gives lower NOYS levels in the lower frequency bands the attenuation effect is considerably reduced at high frequencies and it is in fact inferior to the 9 tube suppressor beyond about 1,000 cycles per sec.

An important factor is that as the aircraft altitude is increased, the atmospheric attenuation is greater at the higher frequencies and, while the 9 tube suppressor is superior with regard to peak frequencies up to an altitude of around 1,000 ft., as the altitude is increased the 21 tube suppressor apparently becomes considerably more efficient. Since the aircraft is likely to be at the higher altitudes when passing over highly populated zones outside the airport boundaries, this indicates one reason why the Boeing 707/120 has the 21 tube suppressor currently installed. Fig. 12 indicates the overall effect of altitude on the attenuation of perceived noise with both the 9 tube and 21 tube suppressors. These results were obtained by tests by Bolt, Beranek & Newman in conjunction with the Boeing Airplane Company[6]. The noise reduction between an aircraft fitted with a 21 tube suppressor and no suppressor is approximately 4 PN dB at 400 ft. and 14 PN dB at 3,000 ft.

2.9. FUTURE POSSIBILITIES FOR JET EFFLUX SUPPRESSION

We must look for a considerably greater reduction in noise levels than the foregoing values for aircraft currently under design with higher thrust. It is difficult to see how this can be achieved using present techniques. one possible line of attack, which has produced considerable noise reduction when used as a ground muffler, consists of a method of injecting water into the jet periphery[9] forming a screen around the efflux. However, since it required a water flow of 2,700 lb per minute on a 5,000 lb. thrust engine to produce an 8 PN dB attenuation at a station 60° from the jet axis at 200 ft. distance, this method would appear to be prohibitive in weight since it would be required during a substantial portion of the early flight phase.

One wonders whether it would be possible to have a steam injection system as a shield, making use of the jet pipe heat, which would require considerably less water. Combustible jet screens may also have some merit since they would gradually burn away during take-off and initial climb and reduce to a minimum the weight penalty for the rest of the flight. Some work is presently being done on electro-magnetic charges in the jet stream in an attempt to laminarise the jet. It is important to achieve the required reduction in ground noise without creating a large drag penalty during the cruise.

Current methods of noise alleviation have a considerable bearing on aircraft operating economy and American Airlines have recently published statistics based on experience with their 707 fleet. The increase in cost resulting from fitting suppressors is over £20 per hour more than for the unsuppressed aircraft; this is due on short range flights for instance, to a 4 per cent increase in flying time due to increased drag and also to an increased fuel consumption of 4 per cent and is based on a suppressor weight of 565 lb. On this basis the penalty appears to work out at approximately a 5 per cent increase in direct operating costs.

2.10. V.T.O.L. CONSIDERATIONS

The recent advent of the very light-weight lifting engines, notably the Rolls-Royce RB.108 type of power plant installed in the Short SC.1 and the dual purpose engine, providing both propulsive and lifting thrust, such as the Bristol Siddeley BSE.53 engine installed in the Hawker P.1127, has opened up the possibility of obtaining practical V.T.O.L. civil aircraft which, all

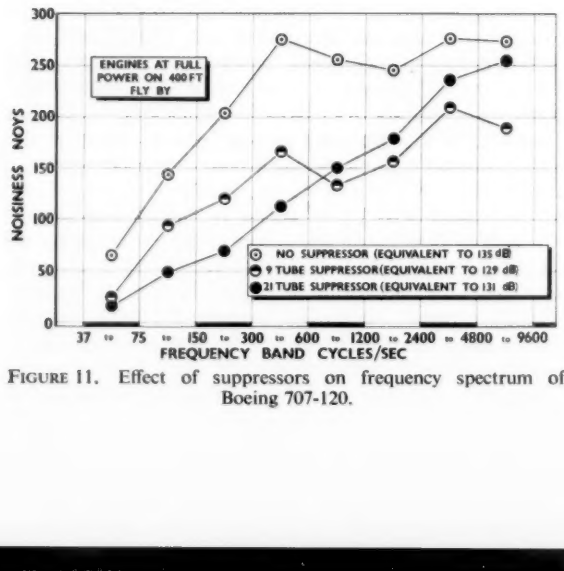
ENGINES AT FULL POWER ON 400 FT FLY BY
NOISINESS NOYS
300
250
200
150
100
50
0
NO SUPPRESSOR (EQUIVALENT TO 135 dB)
9 TUBE SUPPRESSOR (EQUIVALENT TO 129 dB)
21 TUBE SUPPRESSOR (EQUIVALENT TO 131 dB)
37 to 75 to 150 to 300 to 600 to 1200 to 2400 to 4800 to 9600
FREQUENCY BAND CYCLES/SEC

FIGURE 11. Effect of suppressors on frequency spectrum of Boeing 707-120.

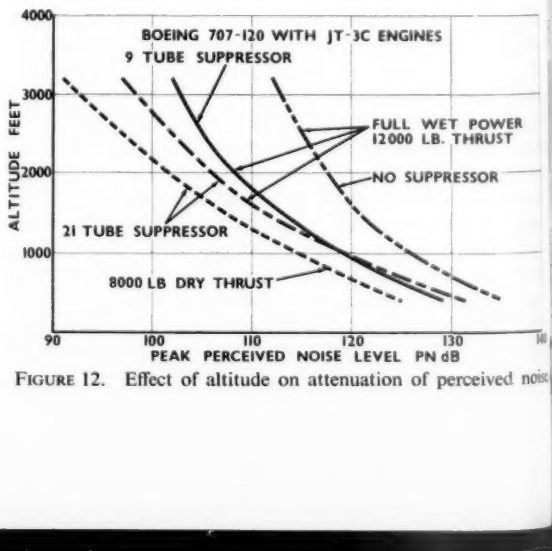

FIGURE 12. Effect of altitude on attenuation of perceived noise

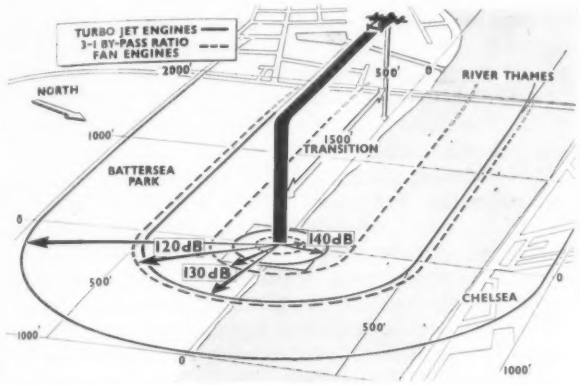

FIGURE 13. Perceived noise levels for jet lift V.T.O.L. aircraft; gross weight 120,000 lb., thrust 132,000 lb.

things being equal, could operate from city-centre to city-centre. While the direct operating costs are likely to be increased by between 30 per cent and 50 per cent over the conventional runway based short range aircraft, the considerably reduced trip time and the saving in taxi fares, and so on, could make the V.T.O.L. aircraft a practical proposition, except again, for the problem of engine noise for which at the moment no solution has been found.

Inherently the V.T.O.L. aircraft is a very high thrust device since, in addition to providing a thrust equal to weight with at least a 10 per cent margin, by the time the thrust for control during ground gust conditions, engine failure, elevated temperature and airport altitude has been taken into account, the installed thrust required usually works out at approximately 1·5 times the weight of the aircraft.

Even using the most optimistic assumptions of the noise characteristics of the quietest ducted fan installations, recent studies have indicated that it is not possible to silence sufficiently the engines for city-centre operation where acceptable noise levels could not be expected to be much higher than those presently experienced within the cities.

Operation from isolated areas outside, but closer into the city than existing airports, might be possible but this type of operation would only show to advantage if saturation had occurred at the present airport facilities and this is not foreseen in the U.K. for some time.

Figure 13 indicates the perceived noise levels for a V.T.O.L. aircraft weighing approximately 120,000 lb. gross, and with an installed lifting thrust of 180,000 lb., but using only 132,000 lb. of this thrust in a normal take-off. Straight jet lift engines and engines with a by-pass ratio of 3 to 1 are both shown, for comparison. The values shown are not corrected for noise reduction due to engine grouping and while this may be substantial it would not be of the order required to reduce the noise to acceptable levels[10].

It is obvious, therefore, that before practical V.T.O.L. aircraft using direct lift can be operated from city-centre, there must be a considerable reduction in the noise levels of even the highest ratio by-pass engines considered.

3. Summary of Propulsive Noise Considerations

The following major points arise from the foregoing examination of the problems of engine noise:

1. The methods of subjective noise measurement are not at present established to a sufficient degree to enable an accurate assessment of the overall annoyance levels likely to be encountered in service for an engine still in the design stage. The resolution of a really reliable datum to which the designer can work is long overdue.
2. The present technique of establishing a noise limit based on a discrete listening point does not appear to be protection against more marked annoyance at other portions of the flight path. It is suggested that more rational and widely applicable noise criteria be established to give a lead to the aircraft and engine designers. While it is realised that there is considerable difficulty in establishing these limits, since the public would obviously like to establish it at zero noise, it should be possible to establish realistic noise limits based on the present state of the art and to establish a target for the future which would give a lead to the Industry on the research and development required to achieve it.
3. While special take-off techniques will possibly make the first generation of Supersonic Transports marginally acceptable, there are likely to be distinct limits in the future on what can be achieved by special flight planning. Increases in the weight of an aircraft during development could make the problem more difficult if the extra thrust required is obtained by increasing the jet velocity.
4. Careful matching of power plant to aircraft will be required on the second generation of large supersonic aircraft cruising between $M=3$ and $M=3\cdot5$ to obtain good economy in the cruise at high supersonic speeds, where a low pressure ratio engine is indicated, and at the same time to obtain the lowest possible noise level in the vicinity of the airport, where a fairly high by-pass ratio engine is indicated. A by-pass solution would probably have to be combined with burning in the by-pass stream to obtain reasonable power during the transonic accelerations and cruise. The variable intake throat which may be necessary for propulsive reasons, may also be used to provide sonic flow conditions in order to contain as much of the compressor noise as possible.
5. Before the aircraft designer can design practical city-centre V.T.O.L. aircraft, using jet lift and large enough to carry a reasonable number of passengers, a major technical breakthrough will be required in engine silencing. This problem is an order of magnitude greater than that for runway-based aircraft and no solution appears to be in sight at the present time.

There is obviously no simple solution to engine noise suppression and, in addition to the points mentioned

it is suggested that a research programme be put into operation as soon as possible to examine the possibilities of considerably reducing the noise at the source. This relatively fundamental programme should be supplemented by a joint development programme between the Aircraft and Engine manufacturers and the appropriate Government establishments to evolve a solution to the problem of excessive propulsive noise compatible with imposing the minimum penalty on aircraft operation and economy.

Some possible avenues of research are suggested below:

(*a*) *Re-Examination of Previous Work on Noise*

Since the problems of jet noise have not been as acute in the past as they are at present, research in this area—both fundamental and *ad hoc*—has not been given the appropriate emphasis. Much of the work started by Industry and the Research Organisations has from time to time been abandoned because of lack of interest or finance—or both. We have now, however, reached the stage where otherwise sound engineering propositions, such as the V.T.O.L. city-centre to city-centre jet lift aircraft, are ruled out on the basis of the ground noise created.

On runway-based high speed transports the attitude that we may be able to scrape by for the next generation still persists. However, since this is by no means certain, it might be well worth while to re-examine the work previously started in this area since some of the past experiments might now have direct application and possibly, with additional experimental work, could provide the basis for establishing the present state of the art in this field.

(*b*) *Basic Research*

While basic research does not lend itself to tight time limits, if any real progress is to be made in the future it is essential that a substantial programme of fundamental research be undertaken immediately. It is also impossible to programme work of this nature specifically since research in one area will uncover the need for research in another. For instance, little is presently known about the interdependence of vibration and acoustic theories. So far as the author knows, there is at present no established theory of turbulence and the relationship of jet noise to suppressor nozzle shape has been gathered largely from experimentation and *ad hoc* testing. Some research on controlled mixing by employing magneto-aerodynamic techniques might well produce appreciable attenuation and flow visualisation techniques could be established to learn more about the fundamental characteristics of turbulence-induced noise. This work might well be done by a selected University.

(*c*) *Establishment of Adequate Noise Assessment Techniques*

As mentioned previously, the present methods of assessment of the annoyance levels of various combinations of sound pressure level and frequency are not by any means universally agreed and subjective experiments should be made to attempt to establish some criteria of acceptable annoyance. It is felt that some of the objections to present methods could be removed by establishing datum values for annoyance by subjective tests in which the human subjects are unaware of being tested.

(*d*) *Experimental Work*

There are many areas which might warrant experimentation: for example, techniques for shielding the jet stream could be fully examined, possibly using steam shields or some type of combustible screen. The mechanisms of absorption and reflection might be investigated in an effort to produce low density forms of insulation and there are many other areas which require attention.

While there is no doubt that this problem is less amenable to the establishment of a time scale for solution than most other problems in Aeronautics, unless some such programme of research and experimentation is started now, the problem of ground noise is likely to become a distinct limiting factor to aeronautical progress in the future.

4. The Sonic Boom

The effect of the sonic boom emitted by a supersonic aircraft in flight is one of the most controversial subjects under discussion at the present time. Recent theoretical and experimental work has indicated that when full account is taken of lift combined with the volume effects for an aircraft flying at high altitude, the sonic boom levels will be considerably higher than previously estimated for a given aircraft weight and speed.

This new information has unfortunately produced a variety of reactions. These vary from an attitude of deep pessimism, which erroneously assumes that this problem will kill the Supersonic Transport for all time, to a super-cautious attitude of "keep it quiet, or it may rock the boat."

The author believes that both of these extremes are unrealistic and that awareness of the problem will go much farther in producing an early solution than will ignoring it. The following discussion of this problem attempts to examine the subject in the light of present knowledge and to explore the effects that it might have on the choice of optimum speed, configuration, size and operation of a future Supersonic Transport.

4.1. EXPERIENCE UP TO THE PRESENT TIME

The problem of sonic booms has been with us for some time due to the flying of the P.1 and F.D.2 supersonic fighters in the U.K. and, more extensively, from the flying of the Century Series supersonic fighters in the U.S.A. and also from the long range flying of the U.S.A.F. B-58 supersonic bomber.

Hundreds of sonic boom incidents have been recorded which vary from slight annoyance to extensive physical damage, such as that experienced in Ottawa, Canada, where over one million dollars worth of damage was caused to a research building under construction as the result of an F.104 flying supersonically at low level. The reactions to booms where no physical damage has occurred have not followed a consistent pattern. Flights of the P.1 and F.D.2 over towns in the U.K. caused many

complaints, while similar flights over comparably populated regions of the North of France caused little complaint. Reactions to sonic booms in different parts of the U.S. have also varied considerably where an aircraft has flown over a long distance at the same speed and altitude. As with all noise problems it is difficult to establish an acceptable datum for sonic boom levels that can be generally applied.

4.2. NATURE OF THE PROBLEM IN THE FUTURE

Within the next ten to fifteen years supersonic civil aircraft will be coming into operation in ever increasing numbers and boom frequency will then be an added problem since, while a certain amount of noise may be accepted by residents who elect to live around an airport, the flight of Supersonic Transports over practically all of the highly populated countries will be a new kind of problem since it affects the less robust human beings who might have retired to a quiet part of the country to escape noise. It would be literally impossible to assume that one could live in an area that at some future date may not be saturated with sonic booms.

It will obviously be necessary to establish a realistically acceptable level for sonic booms in the future since it will be shown that this can have a marked effect on the aircraft configuration and size. The criteria must not only take into account the annoyance factor with regard to human beings, but also the effects on birds and animals and potential damage to property, such as broken windows, and so on.

NOTE: In this paper it has been assumed that overwater supersonic flights would entail no real problem.

Before we discuss the establishment of acceptable sonic boom levels it might help to discuss the causes and nature of the boom.

4.3. NATURE OF THE SONIC BOOM

The human ear is sensitive to rates of change of air pressure. The local flow field around an aircraft in level flight at supersonic speeds causes a continuous series of shock waves which ultimately reach the ground and cause a pressure rise or "jump." Fig. 14 indicates the approximate nature of the flow field and pressure gradients for both the near field pressure rise close to the aircraft and the far field pressure rise where the near field shocks have combined into bow and tail shocks which finally result in an N shaped wave reaching the ground. The pressure rise through the front and rear shocks depends on the aircraft's speed, configuration and altitude. The human ear responds to the sudden pressure rise in much the same manner as it would respond to thunder, except that the boom from an aircraft is of sharper intensity, therefore the shock effects would be more marked and while lightning usually precedes thunder and prepares the victim, no warning is available for the sonic boom.

A number of methods of calculating the sonic boom intensity have been suggested. Whitham and Walkden[11, 12], among others, have carried out investigatory work on this, but the methods considered up to about a year ago did not take into account all of the relevant parameters. In a recent paper to the Royal Aeronautical Society Morris[14] has combined the methods of Hayes[13] and Whitham to predict the shock strength from both volume and lift effects on various combinations of bodies and wings at various weights. Morris has shown that at altitudes above about 40,000 ft. the main shocks will be dominated by the aircraft lift to such an extent that calculation of the shock noise due to lift alone will provide a reasonably close answer. Previously it has been assumed that the boom intensity depended only on the shape and volume, and the lifting terms were neglected. The difference between the old and new theory is shown in Fig. 15. The new theory indicates a lower rate of attenuation with altitude.

There is a limit to the data available from actual test flights of existing aircraft since tests were made at altitudes mainly below 40,000 ft. on aircraft of less than half the gross weight of the predicted Supersonic Transports. The effects of aircraft lift on the sonic boom had therefore not previously been fully appreciated and the sonic boom levels now predicted, using the Morris equations, are considerably higher than previously calculated.

In his paper[14] Morris provides a set of curves from which it is possible to calculate the total boom intensity experienced for various gross weights and aircraft

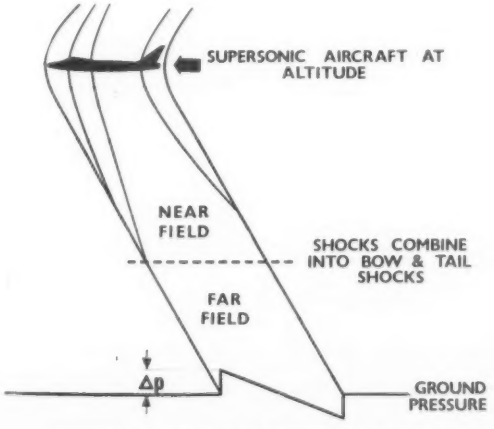

FIGURE 14. Diagram of supersonic flow field.

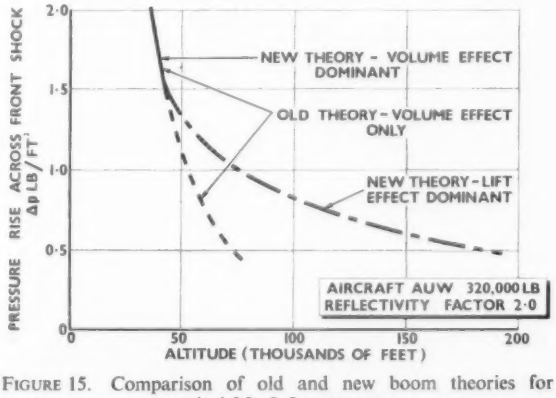

FIGURE 15. Comparison of old and new boom theories for typical $M=2{\cdot}2$ transport.

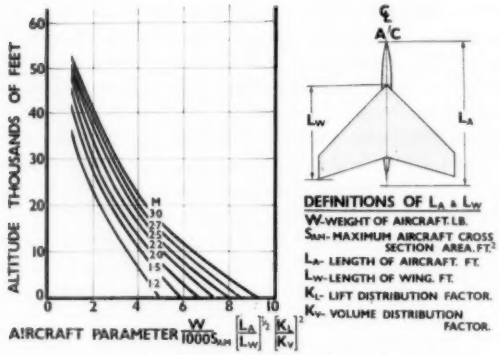
ALTITUDE THOUSANDS OF FEET
AIRCRAFT PARAMETER
DEFINITIONS OF L_A & L_W
W-WEIGHT OF AIRCRAFT LB.
S_{MAX}- MAXIMUM AIRCRAFT CROSS SECTION AREA FT²
L_A- LENGTH OF AIRCRAFT. FT.
L_W- LENGTH OF WING. FT.
K_L- LIFT DISTRIBUTION FACTOR.
K_V- VOLUME DISTRIBUTION FACTOR.

FIGURE 16. Altitude above which lift dominates boom.

altitudes. He assumes a reflectivity factor of two, which means that a person on the ground experiences a pressure level of approximately twice that which he would obtain in free air, due to reflection of the shock waves from the ground.

Morris's assumptions have now been generally accepted and verified by wind tunnel tests carried out in the U.S., with one or two qualifications. For instance, wind tunnel results showed that, while the slope of the far-field N distribution agreed well with Morris's predictions, the sharp-edged peaks were rounded off and, while this may be a result of boundary layer effects on the measuring surface, or model vibrations, the peak values recorded fall on a curve which would indicate an empirical correction factor of 0·75. The final results in this paper have, therefore, been multiplied by this tentative factor K_E as an experimentally derived constant.

Figure 16 shows the altitude, above which the lifting term dominates, for a range of aircraft.

As a result of earlier work the following assumptions appear to be valid. The intensity of the sonic boom is relatively insensitive to:

(*a*) Aircraft configuration.

(*b*) Aircraft speed (above $M=1·15$). *See* Fig. 17.

The most powerful factors as might be expected are, aircraft altitude and gross weight. While it can be shown that boom intensity is reduced to some extent by increased fineness ratio and reduction in aircraft size, the boom intensity cannot be alleviated to any marked extent by

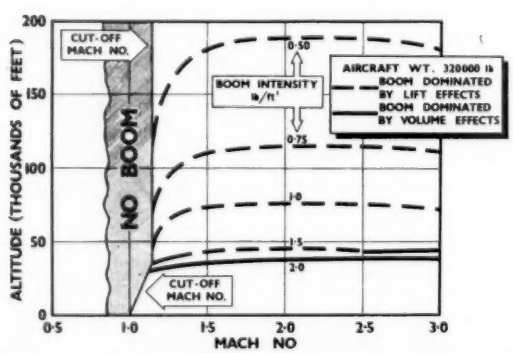

FIGURE 17. Altitude variations with speed for various boom levels—typical supersonic transport.

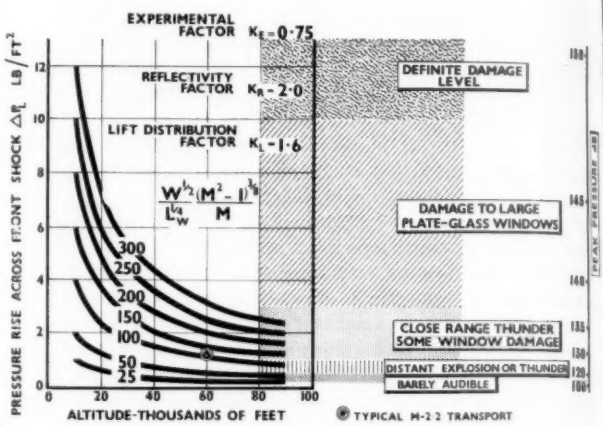
EXPERIMENTAL FACTOR $K_E=0·75$
REFLECTIVITY FACTOR $K_R=2·0$
LIFT DISTRIBUTION FACTOR $K_L=1·6$
$\frac{W^{1/2}(M^2-1)^{3/8}}{L_W^{1/4}M}$
PRESSURE RISE ACROSS FRONT SHOCK ΔP_L LB/FT²
ALTITUDE-THOUSANDS OF FEET
DEFINITE DAMAGE LEVEL
DAMAGE TO LARGE PLATE-GLASS WINDOWS
CLOSE RANGE THUNDER SOME WINDOW DAMAGE
DISTANT EXPLOSION OR THUNDER BARELY AUDIBLE
PEAK PRESSURE dB
TYPICAL M-2·2 TRANSPORT

FIGURE 18. Boom intensity due to lift.

aerodynamic or configuration changes. Fig. 18, which is derived from the paper by Morris, provides a method of obtaining a quick estimate of the boom intensity for a configuration with wings located on the rear of the body, as in most of the present designs for Supersonic Transports. The K_E factor of 0·75 has been used to modify the original curves presented by Morris. An example of a typical Supersonic Transport is shown.

The boom will be heard on each side of the flight path for a distance which is a direct function of aircraft speed and altitude (neglecting atmospheric deviations). At some distance to the side the shock waves will be deflected away from the ground by refraction and there is, therefore, a definite width boundary. As an example, a 320,000 lb. $M=2·2$ aircraft cruising at 60,000 ft. will project a boom approximately 50 to 60 miles wide. (Fig. 19.)

It should be mentioned that the highest boom intensities are caused by acceleration during the climb and by the descent, both of which are normally likely to be over land areas since they occur near to the extreme ends of the flight. Turns and other manoeuvres due to errors in navigation also produce higher intensities

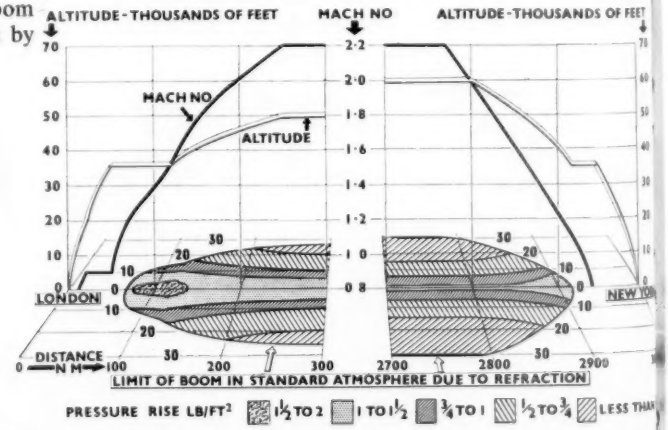
ALTITUDE-THOUSANDS OF FEET
MACH NO
ALTITUDE-THOUSANDS OF FEET
MACH NO.
ALTITUDE
LONDON
NEW YORK
DISTANCE N M
LIMIT OF BOOM IN STANDARD ATMOSPHERE DUE TO REFRACTION
PRESSURE RISE LB/FT² 1½ TO 2 1 TO 1½ ¾ TO 1 ½ TO ¾ LESS THAN

FIGURE 19. Area affected by sonic boom for typical flight of $M=2·2$ transport.

which may, in fact, be two to three times the levels experienced in the cruise. However, these are localised and this particular problem has not been elaborated here since by far the most elusive problem is that of the continuous boom caused by steady flight conditions.

4.4. ACCEPTABILITY CRITERIA

The limits of acceptability for the pressure rise due to a sonic boom have not yet been established, but some attempt has been made to indicate the type of noise generated by various pressure changes by correlation with familiar sounds, such as thunder, and to indicate what might be tolerable and what might be objectionable[15]. Over pressures up to one lb. per sq. ft. are assumed to be tolerable, having about the same noise level as distant thunder. Pressure rises of between one lb. per sq. ft. and 3 lb. per sq. ft. can cause breakage of loosely fitted windows, with the higher pressures in this range creating a noise similar to close range thunder. These are designated as the objectionable ranges. From 3 lb. per sq. ft. upwards, physical damage may occur in much wider areas and the equivalent peak sound pressure level at, for instance, 7 lb. per sq. ft. is equal to about 145 decibels.

For the purpose of illustration it has been assumed in this paper that the highest pressure rise that can be tolerated on the ground is one lb. per sq. ft., since there are indications that this may, in fact, be the limit of acceptance for future supersonic operations, particularly considering the expected frequency.

We will now examine the effect of the foregoing on the flight planning of a typical Supersonic Transport.

4.5. TYPICAL EXAMPLE OF SUPERSONIC TRANSPORT

Figure 20 shows the boom intensity likely to be experienced on the ground from a 100 passenger $M=2\cdot2$ Trans-Atlantic aircraft weighing approximately 320,000 lb. It can be seen that for most of the flight the aircraft is above the one lb. per sq. ft. assumed acceptability criterion.

It has been shown that there is no easy way of reducing sonic boom intensity and it would be necessary to resort to one of the following methods if the boom intensity is, in fact, prohibitive:

(1) Reduce the aircraft speed to subsonic over land areas.

(2) Reduce the aircraft size (it will later be shown that the aircraft weight would have to be reduced to below 200,000 lb. gross for an aircraft cruising at 60,000 ft. to reduce the boom intensity to below one lb. per sq. ft.).

(3) Reduce the aircraft's optimum cruising speed to the level at which there would be no appreciable sonic boom (it has been established that this would be in the order of $M=1\cdot15$ to $M=1\cdot2$).

The method to be followed will depend on the specific aircraft operation under consideration; for instance, on the New York to London flight the amount of over-land flying is very small and flying subsonically over the Western region of England and the approaches to New York would be a reasonable operation. However, on a medium range flight from, say, London to Cairo, where the over land portion of the flight is a high proportion of the total, a $M=2\cdot2$ aircraft would be flying for most of its time at an uneconomical design point; in this case the best solution might be more in line with considerably reducing the size of the aircraft or cruising at a Mach number not exceeding $M=1\cdot2$—both of which solutions would require a new design of aircraft. Examples of the effects of these modifications are shown below.

4.5.1. *Effects of Reducing Over land Speed on $M=2\cdot2$ Transport for Long Range Trans-Oceanic Operation or of Using a Lower Cruise-Speed $M=1\cdot15$ "No Boom" Aircraft*

The datum aircraft will be a 100 passenger aircraft cruising at $M=2\cdot2$, over a stage length of London to New York and weighing about 320,000 lb. gross. It should be mentioned that parametric studies have indicated that economy varies considerably with aircraft size on the Supersonic Transport and, all other things being equal, the largest aircraft is the best economically. Therefore any reduction in the size of aircraft for this long range version would give a high penalty on operating costs (*see* Fig. 21).

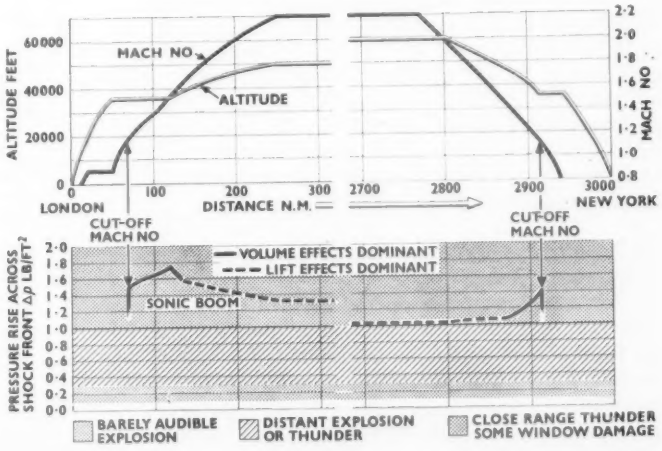

FIGURE 20. Sonic boom on London-New York route for aircraft carrying 100 passengers cruising at $M=2\cdot2$.

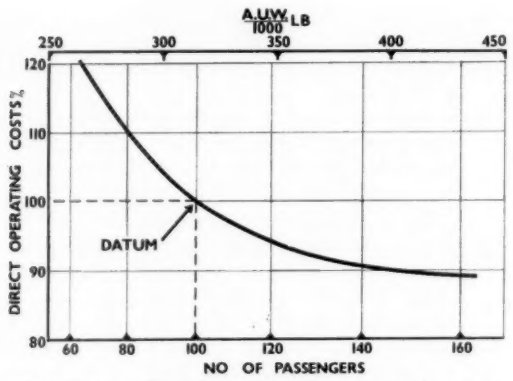

FIGURE 21. Effect of size on operating costs of $M=2{\cdot}2$ trans-Atlantic aircraft.

Figure 22 shows the effect on block speed of reducing aircraft speed to $M=0{\cdot}9$ over land on a flight plan from London to Detroit. The block speed of the $M=2{\cdot}2$ aircraft, assuming no restrictions, is shown for comparison, together with the block speed of an aircraft cruising continuously at $M=1{\cdot}15$, *i.e.* a "no boom" aircraft.

It can be seen that the block time is increased by one hour for an aircraft which has to reduce to subsonic speed overland areas and this same aircraft, which is basically optimised for cruising at $M=2{\cdot}2$, has a block time only 1·2 hrs. shorter than the lower speed "no boom" aircraft which cruises continuously at $M=1{\cdot}15$.

Figure 23 shows the effect on direct operating costs of reducing the $M=2{\cdot}2$ aircraft to subsonic speed over land areas on various routes. The amount of additional subsonic flying that would have to be done in addition to the normal is shown in brackets.

It can be seen that on the London to New York route, which is mainly over the ocean, the Direct Operating Costs are increased by approximately 6 per cent whereas on the London to Detroit route, which requires an additional 850 n.m. of subsonic cruise over land, the penalty is as high as 31 per cent.

It can, therefore, be generally concluded that for the London to New York route the penalties on both block time and operating costs due to sonic boom may not be prohibitive. However, on routes requiring more than a small amount of over land flying, the penalty can be great and where more than, say, 30 per cent of the flight is over land areas, other solutions might be required, such as using a smaller aircraft for the final over land portion of the journey, which might suit the London to Detroit route, or using a "no boom" $M=1{\cdot}15$ aircraft for the complete flight.

4.5.2. *Effect of Reducing Size of Aircraft on Medium Range Routes*

For a medium range operation, such as London to Gibraltar or London to Cairo where practically all of the flight is over land, it will be necessary to restrict the aircraft size to that which will generate an acceptable boom intensity.

Figure 24 shows the minimum cruise altitude for various boom levels for aircraft of various gross weights and with a typical "slender body" configuration. It can be seen that for an aircraft cruising at an altitude of around 60,000 ft., which is a reasonable altitude for economic cruise at high speed, the weight of the aircraft would have to be restricted to below 200,000 lb. for operations over land areas in order to have an acceptable sonic boom intensity of less than one lb. per sq. ft.

Since it has been shown that for best economy the aircraft should be as large as possible we should now examine the effect on economy of restricting the aircraft to this gross weight. Fig. 25 shows a typical "work capacity" curve in terms of payload-nautical-miles versus aircraft gross weight for piston engined transports, turboprops and subsonic turbojets. On the right-hand side of the chart are shown the results of parametric studies on a $M=2{\cdot}2$ transport plotted for various sizes and passenger densities varying from 50 to 200. The approximate weight ratio of freight to passengers is 10 per cent. The thick outside $M=2{\cdot}2$ line is plotted as a continuous tangent through the optimum points on the individual curves and indicates the very best work-capacity that can be achieved for this family of aircraft for a given all-up weight.

It is realised that this method has limitations since the exchange of payload and range is not infinitely variable. However, this can be taken into account by using the portion of the curves appropriate to the number of passengers considered, which is indicated on various positions on the line. This line can, therefore, be used to produce a quick assessment of optimum aircraft range and payload versus gross weight for a $M=2{\cdot}2$ aircraft.

It is interesting to note that these curves collapse on to one master curve when aircraft speed is taken into account, giving a total productivity parameter in terms of the product of ton-miles and miles per hour (*see* Fig. 26). This curve is based on over 60 aircraft[7] and almost all of them lie surprisingly close to the curve.

If we accept this trend between productivity and gross weight of aircraft and we assume that for an acceptable sonic boom level we cannot exceed a gross

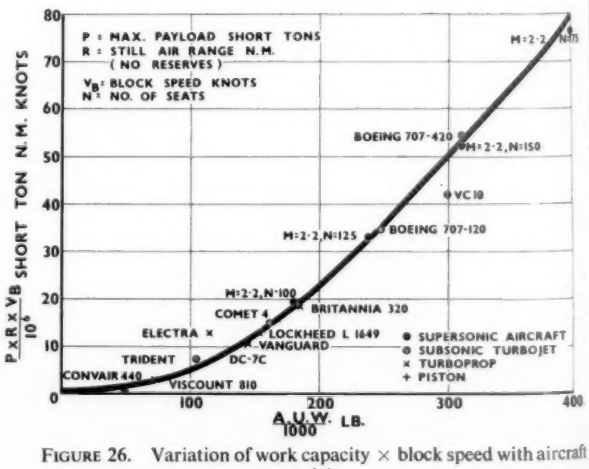

FIGURE 26. Variation of work capacity × block speed with aircraft weight.

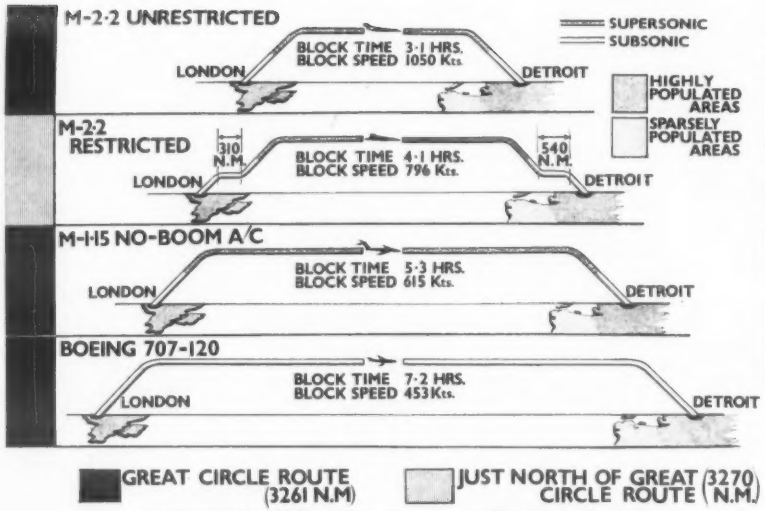

FIGURE 22. Effect of sonic boom on flight planning.

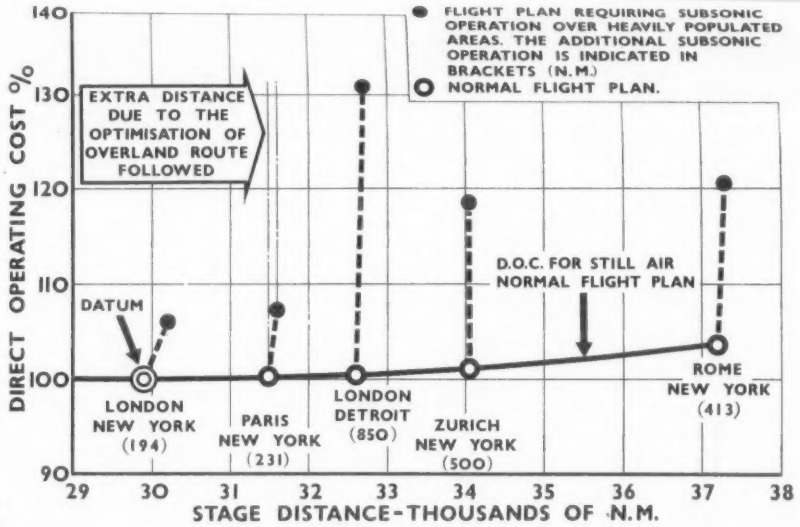

FIGURE 23. Effect of increased subsonic operation on operating costs of $M = 2{\cdot}2$ transport.

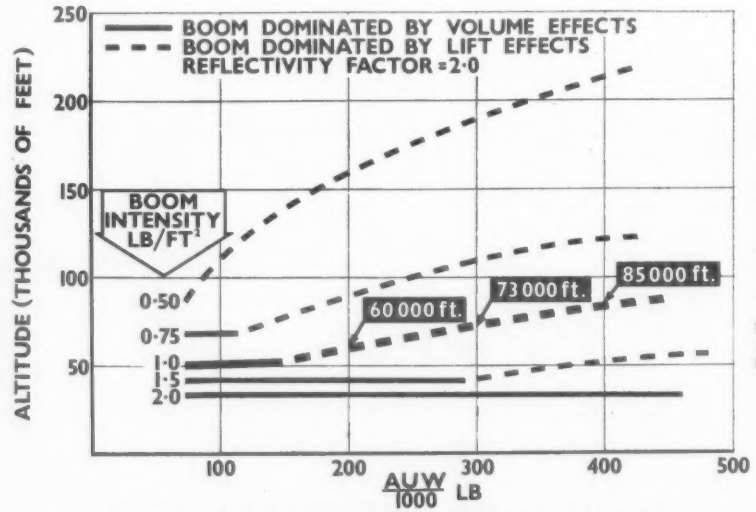

FIGURE 24. Altitude variations with weight for various boom levels—typical supersonic transport.

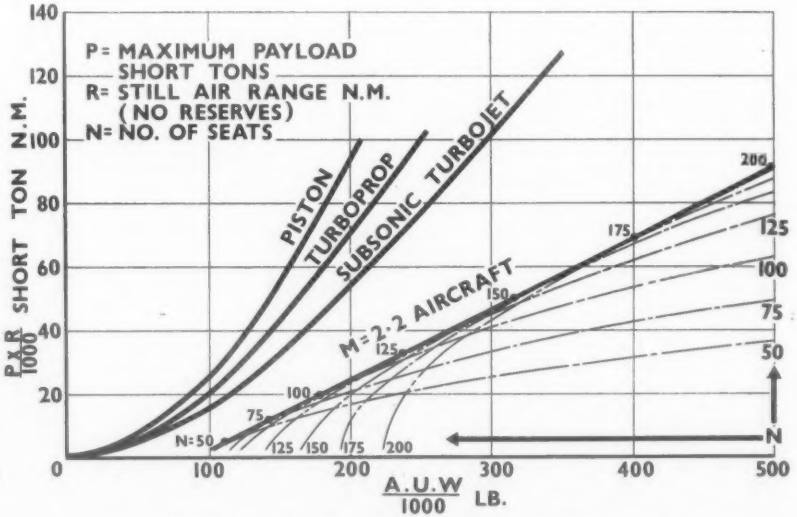

FIGURE 25. Variation of work capacity with aircraft weight.

weight of 200,000 lb., then we can establish the size and configuration of the $M=2\cdot2$ aircraft which would be acceptable over land areas. It can be seen to have a "work capacity" value of 25,000 short ton nautical miles, which is equivalent to about 220,000 seat n.m. plus freight, and the points lie close to the 110 seat optimum position on the curve. This would indicate a still-air range without reserves of 2,000 nautical miles or a practical stage distance with reserves in the order of 1,200 nautical miles.

While a smaller payload could be carried for a longer range on an aircraft optimised to that particular condition at the same gross weight, parametric studies would be necessary to determine the exact exchange rate of these variables. An example might help to clarify the factors involved.

The fuel required for a Supersonic Transport weighing 200,000 lb. would probably be in the order of 40 per cent of the gross weight or 80,000 lb., of which about 50,000 lb. would affect the range, the rest being for allowances, and so on. The payload would, however, be in the order of less than 10 per cent or 20,000 lb. It can be seen, therefore, that trading off a high proportion of the payload to obtain a longer range by increasing the fuel weight is not going to improve the productivity since reducing the payload by 50 per cent is only likely to increase the range by about 20 per cent, giving a productivity around 60 per cent of that of the aircraft with the larger payload.

We have roughly established then, that an aircraft cruising over land areas at $M=2\cdot2$ may be restricted to a weight of about 200,000 lb. gross, which would be consistent with a typical payload of 110 passengers and operating over a *stage length* of approximately 1,200 n.m. The operating economy would be somewhat worse than the present subsonic jets operating over these routes, especially in view of the smaller size applicable to the supersonic aircraft because of sonic boom restriction.

However, the economy would certainly be better than for a larger and heavier aircraft which might have to cruise for a long distance at subsonic speed over land. Fig. 27 provides a direct operating cost datum for the optimised $M=2\cdot2$ curves from Fig. 25. As mentioned previously this curve does not represent a given range or payload; the appropriate range-payload combination which provides optimum productivity at any given gross weight is indicated at the relevant part of the curve, N being number of passengers, and R indicating still-air range.

The datum point is taken as 200,000 lb. gross weight which is the estimated weight for acceptable boom intensity of the above corresponding aircraft carrying 110 passengers and with a still-air range of 2,000 n.m., *i.e.* 1,200 n.m. stage length.

The penalty for having to make a subsonic portion of the cruise for higher weights of aircraft is clearly indicated for 500 n.m. and 1,000 n.m. subsonic distances. It can be seen that the smaller aircraft cruising continuously at its design point of $M=2\cdot2$ is considerably more economical than the larger aircraft on routes where more than about 200 or 300 miles of subsonic flight are necessary on the heavier aircraft because of boom effects.

4.6. POSSIBILITIES FOR ALLEVIATING SOME OF THESE PROBLEMS

It has been fairly well established that the nature of the sonic boom is such that it is not amenable to large reduction by changes in aircraft configuration or normal aerodynamic developments. Reduction in aircraft weight for a given job is the most powerful factor and, on this basis, it is thought to be worthwhile to examine the effects which laminarisation might have on the achievement of greater productivity for a given gross weight of aircraft.

Figure 28 indicates the result of a study to ascertain the increase in productivity which might be achieved by laminar flow control similar to that designed for the Northrop WB.66D. It is assumed that 90 per cent of the aircraft's outer skin is fitted with laminar flow control resulting in a marked drag reduction which, in turn, saves sufficient fuel to allow for an increase in aircraft size to accommodate more passengers. The boom intensity levels corresponding to the various gross weights are shown. The slant on the boom intensity lines is caused by the fact that the laminarised aircraft would be larger for the same gross weight and able to carry more payload. Since it is likely that the extra passengers would be

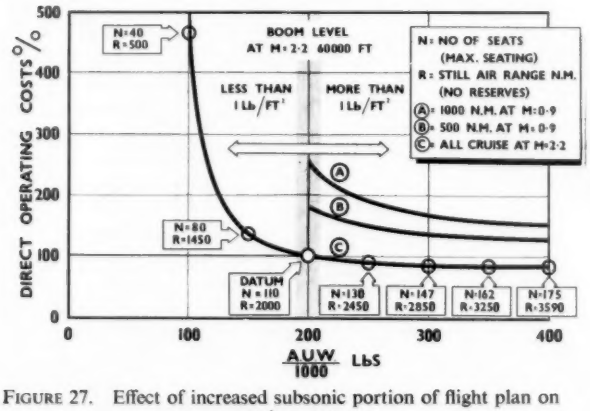

FIGURE 27. Effect of increased subsonic portion of flight plan on operating costs.

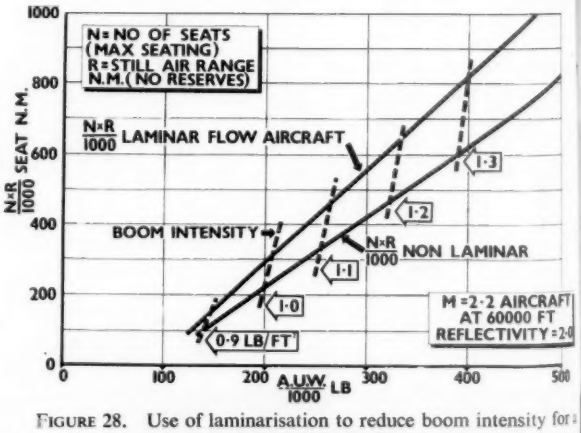

FIGURE 28. Use of laminarisation to reduce boom intensity for a given work capacity.

accommodated in a longer cabin, leaving the cabin cross-section as it is, this would result in a somewhat higher fineness ratio and this has a slight alleviating effect on the boom intensity, allowing an increase in gross weight for the same intensity. It can be seen from this chart that for an aircraft limited to 200,000 lb. gross weight, it would be possible to achieve a seat-nautical-mile productivity factor of 290,000 which is about 32 per cent higher than was achieved without laminarisation. Allowing for the fact that the increased fineness ratio might also allow the aircraft weight to go to 210,000 for a one lb. per sq. ft. pressure rise the "work-capacity" factor then becomes 310,000, or some 40 per cent higher than for the unlaminarised aircraft.

The figures shown are not intended to represent an actual design of aircraft but are included to show the possible effect that laminarisation might have on the sonic boom problem. From the foregoing we can conclude, therefore, that laminarisation might well emerge as a means of overcoming some of the adverse effects of the sonic boom.

5. Summary of Sonic Boom Considerations

Recent information on the sonic boom, which indicates that boom intensity levels for large high flying Supersonic Transports might be up to 100 per cent higher than previously calculated, could have far reaching implications on aircraft size and operations. The full extent of the problems can only be ascertained when reliable acceptable boom intensity levels are established and tests to establish these should be made immediately.

An examination of the possible effects of the establishment of boom intensity limitations has indicated the following trends:

1. The Trans-Atlantic (London to New York) Supersonic Transport is not likely to suffer a large increase in operating cost due to sonic boom limitations since it is almost entirely an over-ocean route. However, since its use may be severely restricted on other routes and quantities of aircraft may therefore be lower, operating costs may be adversely affected on this score.
2. Supersonic aircraft on Trans-Atlantic routes other than London to New York, for instance, London to Detroit, New York to Rome, are likely to suffer a considerable penalty in operating costs due to the large over land portion of the flight involving subsonic speed and consequent increase in block time. There is no current data which indicates that a marked reduction in sonic boom levels can be achieved for these large aircraft and reducing speed to subsonic appears to be the only solution.
3. The possible restrictions placed on the large supersonic aircraft may have a marked effect on all route equipment. In the past it has been the general rule to reallocate the large Trans-Atlantic aircraft to domestic routes when the later equipment is purchased for the trans-oceanic "Blue Riband" flights.
   The sonic boom phenomena may preclude this pattern being followed in the future and may mean more specialised aircraft for various routes.
4. It may not be possible to fly supersonic civil aircraft weighing more than 200,000 lb. over highly populated areas, which would have serious economic implications on the domestic routes and European operations and particularly on the U.S. domestic routes.
5. Laminarisation may be an answer to (4) since it allows a higher percentage of payload to be carried for a given gross weight which would go some way to relieving the effects of weight restrictions.
6. Some thought should be given to the possibility of designing a "no boom" supersonic aircraft. It is indicated that this aircraft would have a maximum speed of between $M=1{\cdot}15$ and $M=1{\cdot}2$. If an aircraft of this configuration could be shown to be economically competitive with present transports it would show a speed advantage of close to 40 per cent on present equipment and would not be restricted to any particular route structure.

It is not the purpose of this paper to cast a cloak of gloom over the problem of the sonic boom, or in fact to over-emphasise it. The main purpose of this summary is to highlight some of the implications of these problems so that:

(*a*) The authorities will put some effort into establishing a criterion to which the aircraft designer can work, based on adequate flight tests at the frequency expected for future transport operations and also so that:

(*b*) The designer can at least realise some of the implications involved in the limits which might be set and give some thought to dealing with this problem, which might possibly turn out to be one of the most significant in this decade.

6. The Increasing Ratio of High to Low Speed

The ratio of the design cruise speed to the approach speed of an aircraft has been considered in the past as some measure of the difficulty of designing the type since they are obviously conflicting requirements requiring, on the one hand, the maximum speed for rapid transit between terminals and, on the other hand, the minimum controllable speed for approach and landing to enable the aircraft to comply with traffic control in congested areas and to land in minimum airfield length.

Figure 29 shows that in the two decades from 1930 to 1950 there was little change in this ratio which was in the order of 2 to 1[7]. During the past 10 years, however, it has increased to almost 4 to 1 and the Supersonic Transport scheduled to be in operation on the World Airlines by 1970-75 will require an increase in this ratio to between 8 to 1 and 10 to 1.

It is generally agreed that approach speeds should not be allowed to rise above 150 kts. or 173 m.p.h., in the foreseeable future. This is likely to become a major problem in the design of even the first generation of

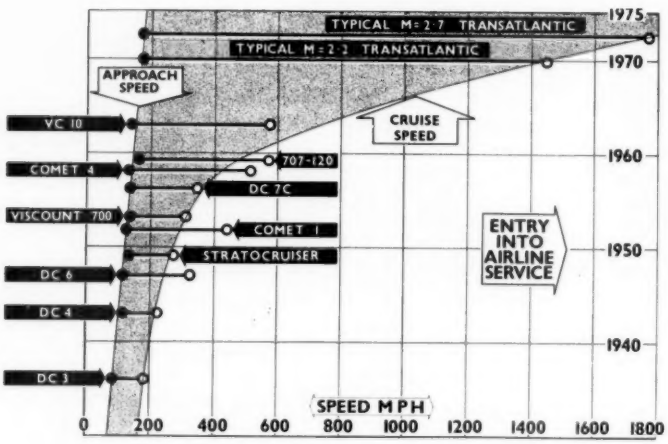

FIGURE 29. The increasing difference between cruise and approach speeds.

Supersonic Transports and more especially for aircraft designed to cruise at over $M=2\cdot5$ since the achievement of a sufficiently low drag or high L/D at this cruise speed and above is not necessarily compatible with the requirement of low approach speed coupled with adequate natural stability and control.

Synthetic stability can be built into the aircraft to overcome this to some extent but this requires an exceptional degree of reliability in the control system.

There is a noticeable difference between the approach of the U.K. and the U.S. in this regard. While the U.K. research organisations have concentrated mainly on fixed geometry solutions for the Supersonic Transport, practically all the recent studies in the U.S. have been based on some form of variable geometry wing in an attempt to get the best compromise between high and low speed characteristics.

This difference in philosophy is due, in some measure, to the fact that the U.S. are concentrating on a cruise speed of $M=3$, and indicates that they do not believe that an adequate solution can be found using fixed geometry at this speed, while the U.K. is concentrating on $M=2\cdot2$ where the problem is not quite as acute.

The author believes, however, that this is still one of the most critical areas in the design of a supersonic civil aircraft and that some discussion of it may be worth while, especially since it affects the economy of the aircraft to a great degree.

6.1. NATURE OF THE PROBLEM

The achievement of a sufficiently high value of L/D in the supersonic cruise, to enable the aircraft to have comparable economy with the present large subsonic jets, calls for a high degree of optimisation of wing plan form and section and special treatment of the combined wing-fuselage combination. The resulting shape, with its very low aspect ratio and consequently small aileron power, departs considerably from the optimum shape for obtaining a high lift coefficient for approach and landing and good controllability characteristics at these low speeds, also it does not possess particularly good subsonic characteristics in the other "off design" portions of the flight. The low wing loading compensates in some measure for the low lift coefficient but the required lift during landing is achieved at large angles of attack. This configuration has a high rolling tendency, even at mild degrees of sideslip which is aggravated by the high values of incidence required.

This configuration of aircraft also has a considerably higher minimum drag speed than present subsonic jets and this is an important factor in the low level holding pattern and during the approach. The significance of this can be better appreciated if the problems of traffic control at London Airport are discussed.

6.2. EFFECT OF LOW SPEED CHARACTERISTICS ON TRAFFIC CONTROL

There are at present several hundred take-off and landing completions at London Airport every day and a conservative estimate of the number that will be applicable by 1970 is one take-off or landing every 45 sec. It is estimated that, during peak periods, there will be over 50 aircraft in the Control Pattern at one time.

In this environment it would not be practical to apply special rules to Supersonic Transports once they have entered the traffic control area and, with such congested air space, the allocation of special holding areas and faster approach speeds would be impractical. It can therefore be assumed that the supersonic civil aircraft will have to operate under substantially the same rules as present subsonic jets.

This problem was highlighted in the recent collision between the United Airlines DC-8 and a T.W.A. Constellation over New York. The DC-8 was estimated to be 11 miles beyond its clearing limit when it collided with the T.W.A. aircraft over Staten Island. The F.A.A. have now ruled that speed must be limited to that which permits rapid manoeuvres to be made within the terminal area.

There are at present two holding areas for London Airport, one to the South East over Epsom, the other to the North East over Watford. These areas are approximately 15 miles long and 7½ miles wide and have been allocated to have the minimum effect on the major traffic flow, which is predominantly from the North West and the South.

Assuming that these holding areas will still apply to the Supersonic Transport, if errors in navigation and wind are taken into account, the turning radius for which the aircraft will have to be designed is something less than 3 n.m. and is probably closer to 2½ n.m. It is also important that a separation distance of at least 5 n.m. between aircraft in this area is maintained.

To operate within these limits at an altitude of below 10,000 ft. it is necessary to make a rate one turn with an angle of bank of about 30° at a speed of approximately 200 kts. E.A.S. The g would be of the order of 1·20.

It is presently considered that these combined values of bank angle and g are about the maximum which passengers will tolerate as a normal procedure. It is therefore desirable that the aircraft have reasonable economical stacking characteristics at a speed of about 200 kts. E.A.S. and here the minimum drag speed is an important factor.

6.3. MINIMUM DRAG SPEED

It can be shown that the best endurance speed for a jet powered aircraft is close to the minimum drag speed, although it is usually required to fly the aircraft slightly above the minimum drag speed to have some margin of speed stability. For an aircraft flying at lower than minimum drag speed any reduction in speed increases the drag and causes a further reduction in speed. An increase in speed causes a reduction in drag and further increase in speed. In other words, the aircraft is in an unstable speed condition. While automatic throttle control can be used, if the aircraft is operated appreciably below the minimum drag speed, rapid and large changes in thrust settings may be required to avoid a somewhat erratic flight path during the critical phases during approach.

Operating the aircraft much below the minimum drag speed also causes rapid drag increase in the turns (which account for more than 60 per cent of the total stacking time in the low level holding pattern outlined above).

If the minimum drag speed is 300 kts. and the aircraft is holding at 200 kts., the mean drag can be as high as 50 per cent above the minimum drag value, giving a considerable increase in fuel consumed during the stacking procedure.

It has been shown then, that the aircraft should have a low level minimum drag speed as close to 200 kts. as possible if the fuel used during low level stacking is not to be prohibitive and to provide a reasonably comfortable approach in average weather. This value of minimum drag speed is difficult to achieve on a fixed geometry aircraft designed to cruise at $M=2$ to $M=3$ and a value of 260 kts. to 300 kts. is more compatible with the fixed geometry solutions examined so far and using "state of the art" techniques.

6.4. APPROACH SPEED

As mentioned previously, it is generally agreed that the approach speed should not exceed 150 kts. and 140 kts. is a desirable design target for the Supersonic Transport.

It is also essential that the pilot has adequate view for safety during the approach and this presents a problem on the fixed geometry supersonic aircraft since very high angles of attack are needed to achieve the C_L required at the speeds quoted. It is estimated for the slender delta, for instance, that an angle of attack of about 15° is necessary to achieve the required trimmed C_L of 0·46 to 150 kts. and a drooped nose would be required to reduce this angle relative to the pilot. (The Americans are understood to have chosen a maximum angle of 12° for approach, to obtain a reasonable view for the pilot).

6.5. OTHER CONSIDERATIONS OF APPROACH SPEED

On the very low aspect ratio fixed geometry supersonic aircraft, where flaps or other high lift devices are relatively ineffective, the approach speed can only be reduced by a corresponding increase in wing area and this inevitably results in an increase in aircraft gross weight. Fig. 30(a) indicates the increase in gross weight and the resulting increase in operating costs which might be expected as approach speed is reduced for a $M=2·7$ aircraft of 350,000 lb. gross weight with a datum approach speed of 150 kts. It can be seen that a reduction of 10 kts. results in a gross weight increase of 12,000 lb. The powerful effect of approach speed on B.C.A.R. field length is shown in Fig. 30(b).

6.6. ALTERNATIVE CONFIGURATIONS FOR SUPERSONIC TRANSPORTS

The above low speed problems are causing some concern and a variety of solutions is being examined.

Figure 31 shows some of the suggestions being put forward on both sides of the Atlantic. The diagrams are self-explanatory and indicate some possible contenders in each field, from the highly "area-ruled" $M=1·2$ aircraft to the $M=3+$ "favourable-interference" configuration favoured by North American Aviation Inc., as a derivative of the B—70.

The "zero approach speed" V.T.O.L. transport of the type suggested by Dr. Griffiths is also shown since, while independent investigations have not substantiated the feasibility of the V.T.O.L. supersonic civil aircraft at currently suggested cruising speeds, it may well turn out to be the most practical solution when aircraft are designed to cruise at speeds in excess of, say, $M=4$, when all the problems that have been discussed here on

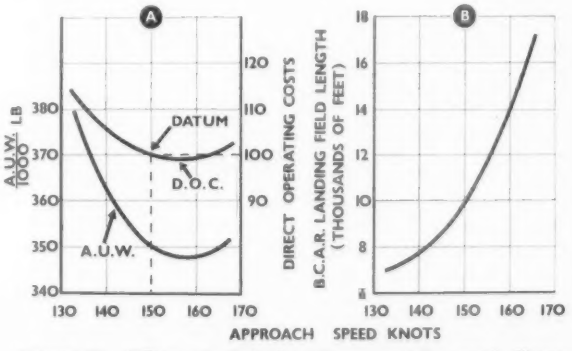

FIGURE 30. Effect of designing for approach speed—Trans-Atlantic aircraft cruising at $M=2·7$ with 120 passengers.

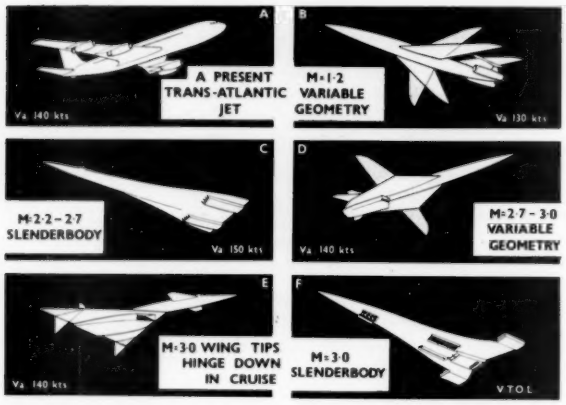

FIGURE 31. Some possible supersonic transport configurations.

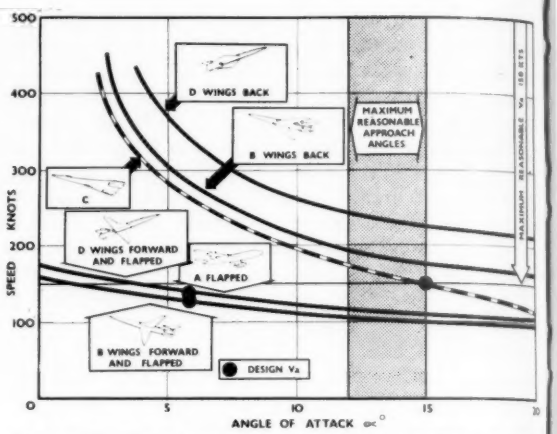

FIGURE 32. Variation of speed with angle of attack for various transport configurations.

approach and landing speeds will be increased enormously. Before this solution could be put into practical operation however, the problems of noise from the lifting engines will have to be solved.

The sort of approach speeds which might be expected from each of the configurations shown is indicated below each diagram, and Fig. 32 indicates the speed versus angle of attack which could be expected of configurations *B*, *C* and *D*. The difficulty of achieving the required approach speed within a reasonable angle of attack for the fixed geometry solution is clearly indicated.

Solutions currently suggested for reducing take-off and landing speeds on subsonic aircraft, such as the jet flap, are not considered to be applicable to low aspect ratio supersonic aircraft since they require a relatively large wing span to achieve the desired result.

6.7. VARIABLE GEOMETRY

While the variable geometry solutions look promising with regard to approach speed and, since a high aspect ratio is available they will obviously be more efficient for all of the subsonic cases, there will be a weight penalty of at least 3 per cent of the gross weight for the variable sweep mechanism and structure. The balance between the increased structure weight and the reduced fuel weight would have to be assessed very carefully.

Also, for the $M=2\cdot7$ to $M=3$ aircraft indicated in Fig. 31(*d*) the wing will probably need a high degree of camber and twist to achieve the required pressure gradients and drag associated with this speed and this will be an embarrassment in the swept-forward conditions. The $M=1\cdot2$ aircraft will not, of course, present as difficult a problem in this regard.

6.8. OTHER IMPORTANT SUBSONIC SEGMENTS

In addition to the approach and landing phases the other subsonic areas are also worth considering since they affect the economy and the size of the aircraft.

Figure 33 shows a typical flight plan for a $M=2\cdot7$ aircraft flying between London and New York. The percentage of fuel used is shown at each segment and it can be seen that less than 50 per cent of the fuel is used for cruise, the remainder being for climb, descent and reserves, or the "off design" cases, and at least 30 per cent of this fuel is carried for the subsonic segments. This emphasises the need for a configuration giving optimum overall efficiency, rather than one designed specifically for the cruise condition.

The higher proportion of subsonic flying which is likely to be required over land areas due to the sonic boom problem, which was dealt with in the previous sections of this paper, implies even greater need for optimum overall efficiency.

7. Summary of Speed Ratio Considerations

The problem of achieving the high supersonic L/D required for range efficiency during cruise, coupled with adequate low speed characteristics including the low minimum drag speed desirable in the holding and approach phases, is going to require a great deal of effort on the part of the designer, especially for aircraft cruising at speeds between $M=2$ and $M=3+$, with increasing difficulty at the higher speeds.

It is believed that this problem is the main reason why the Americans have not yet fixed on what they consider to be optimum solution for the $M=3$ transport and why they are putting considerable emphasis on variable geometry solutions.

This problem can only be resolved by extensive wind tunnel programmes and a full scale research programme, including the flight testing of high speed variable geometry designs.

8. General Summary

In this lecture I have attempted to highlight a few of the problems which currently face the designer of high speed civil aircraft and, while each has been discussed on an individual basis, these problems are, to a large extent, interdependent.

The large $M=2$ to $M=3$ Supersonic Transport is likely to emit an unacceptably large sonic boom which will preclude its use over land areas and is also likely to require a take-off thrust which will, at best, make it marginally acceptable based on present airport noise

regulations for daytime operation. Any reduction in acceptable noise levels or rationalisation of the acceptable noise pattern is likely to increase the problem. Fixed geometry solutions will also tend to have marginal low speed characteristics during the approach.

Although, as mentioned previously, the purpose of this paper is to stimulate discussion of the problems rather than to attempt to provide specific solutions to them, it has been shown that there are two possible developments which may have a distinct bearing on their solution.

(*a*) *Laminarisation*

Up to the present time laminarisation has been aimed towards increasing the payload for a given weight and range, or increasing the range for a given payload and weight. Laminarisation might now be suggested as a partial solution to the sonic boom problem for over land routes since it increases the work capacity of an aircraft, the maximum gross weight of which is limited by the sonic boom. By the employment of a high degree of laminarisation it might be possible to achieve operating costs comparable with the larger subsonic aircraft, provided that the extra cost of developing and installing the laminar flow control is amortised over a reasonable number of aircraft.

The laminarised aircraft usually has a lower wing loading than the unlaminarised for a given weight in order to achieve the required balance between profile and induced drag and this is likely to result in improved low speed characteristics. The resulting aircraft will also require less take-off thrust which in turn, will reduce the problem of ground noise.

NOTE: The optimisation of the ratio of induced drag to profile drag on a laminarised aircraft usually results not only in a larger wing area or lower wing loading, but also in a reduced cruising altitude. Since altitude has in itself a powerful effect on the sonic boom, the examples shown in this paper (Fig. 28) include a weight penalty due to increasing the thrust in order to cruise at the same altitude as the non-laminar aircraft.

(*b*) *Variable Geometry*

The second possible solution to supersonic flying over land which has been discussed is the $M=1{\cdot}15$ aircraft employing variable geometry. The block speed is about 30 per cent better than present subsonic jets and, since there would be no "boom" limit to the aircraft size and weight, this solution can be considered on its own merits by comparison with the costs of present subsonic aircraft of similar weights. Since the aircraft would have to have a high degree of wing sweep and area ruling to obtain the required lift to drag ratio for economical cruise, it would require variable geometry with a much reduced angle of sweep for approach and landing. A higher take-off C_L would be available with this configuration and, in general, less take-off thrust would be required than for the fixed geometry aircraft, resulting in a lower ground noise level; however, this would obviously depend on the aircraft size and weight.

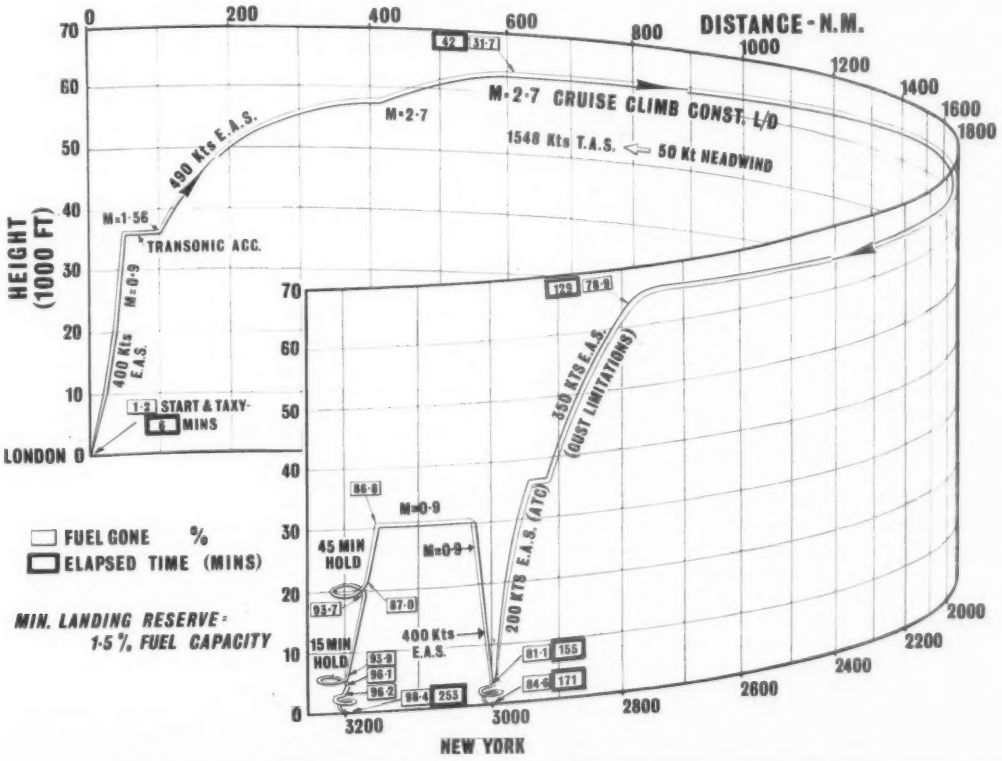

FIGURE 33. Typical flight plan for $M=2{\cdot}7$ supersonic transport non-stop trans-Atlantic.

There are, without doubt, other solutions to the problems discussed and I look forward to the day when their solution has made this paper out of date. However, I feel very strongly that an increased awareness of these problems now might prevent us from having to face the serious repercussions that may result from designing large supersonic civil aircraft without proper regard to the limitations which might later be imposed, especially regarding sonic booms.

The relatively phenomenal rate of progress in aeronautical engineering which has occurred in recent years has tended to lull us into the philosophy that the public will accept whatever we have to offer, provided that it is reasonably sound economically.

There is no guarantee that an increased rate of progress will automatically provide either the right answers or even acceptable ones and, unless we pause now and again and assess the problems which might limit our progress in the future if they are not given sufficient attention now, we are in danger of being in the position of the motorist who opens the throttle and makes very good time in the wrong direction because he did not take time to look at his road map.

In the main text and in the recommendations contained in the summaries at the conclusion of the discussion of each problem I have attempted to draw a rough "road map" of possible avenues of research and study aimed at acquiring greater knowledge on these problems and their possible solution. If this paper stimulates some discussion and appropriate action on the problems discussed it will have fulfilled its purpose.

I wish to emphasise that the opinions expressed in this lecture are personal and do not necessarily coincide with those of Hawker Siddeley Aviation Ltd.

I would like to take this opportunity to thank my colleagues in the Advanced Projects Group of Hawker Siddeley Aviation for their assistance in preparing this paper and in particular, to thank Mr. Bernard Patrick for his great personal help. I appreciated particularly his ability to transpose my illegible scribbling and ideas into readable charts.

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TECHNICAL NOTES

Surface Preparation of Aluminium Alloys for Metal Spraying

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IN THE COURSE of an investigation of the use of sprayed metal coatings for protecting high strength aluminium alloys against stress corrosion, the critical importance of adequate surface preparation before spraying has become clear. Detailed results showing the high degree of protection provided by metal spraying, even to parts stressed in the short transverse direction, will be published in full later, but it seems advisable now to call to the attention of aircraft manufacturers and others who may be considering adopting this method of protection the importance of the blasting treatment used before metal spraying.

In the earlier tests carried out in this investigation HE.15 and DTD.683 specimens were steel grit blasted prior to metal spraying with aluminium or aluminium alloy. Complete coatings of suitably low copper content gave excellent results under test conditions selected to give much shorter lives of unprotected material than would normally be experienced in service. There were a few early failures but most of the specimens protected in this way are still on test; the lives of specimens stressed in the short transverse direction, for example, have increased from less than 50 days to over four and a half years.

Since it was considered preferable to blast with alumina to avoid contamination of the metal surface with iron powder a set of short transverse DTD.683 specimens was subsequently prepared, blasting with alumina grit before metal spraying. The alumina used was of fine particle size (100 per cent less than 0·003 in. mesh and 35 per cent less than 0·001 in.). The results obtained in this series of tests were most unsatisfactory, twenty-four out of thirty-six metal sprayed specimens failing in less than 40 days. It was obvious that the adhesion between the sprayed metal coating and the underlying metal was very poor on these specimens and this was attributed to the use of excessively fine alumina for grit blasting. Two further sets of specimens were therefore prepared, one set being blasted with coarser alumina grit (65 per cent in the range 0·006 to 0·012 in. mesh) and the other with steel grit (87 per cent in the range 0·008 to 0·028 in. mesh). These specimens have now been on test for 500 days and there have been only two failures of metal sprayed specimens, one after 140 and the other after 250 days.

It is concluded from these results that high strength aluminium alloys can be satisfactorily protected against stress corrosion by suitable sprayed metal coatings of aluminium or aluminium alloy provided that the grit blasting preparatory to metal spraying affords adequate keying for satisfactory adhesion of the sprayed metal coating. Blasting with a fine grade of alumina does not give satisfactory results, at least in the case of DTD.683 stressed in the short transverse direction. It is believed that the isolated early failures in tests in which most metal sprayed specimens gave very long lives were due to poor adhesion of the coatings on the specimens that failed. This would be more liable to occur on the very small ($1\frac{1}{4} \times \frac{3}{8} \times 0{\cdot}04$ in.) specimens used for the tests than on actual aircraft components, owing to the practical difficulty of preparing and spraying such small specimens.

Sprayed metal coatings are also most effective in preventing exfoliation and general corrosion of high strength aluminium alloys. The influence of the blasting treatment employed before metal spraying has not been investigated in this connection, but it is presumably still essential to ensure good adhesion of the sprayed metal coating to the base metal.

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On the Effect of Shock-Induced Turbulent Separation on the Shock-Wave Position in a Nozzle

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1. Introduction

Arguments based on the analogy with nozzle flows played an important part[1] in the development of our understanding of the effect of shock-induced separation on the flow past aerofoils at transonic speeds. For aerofoils our knowledge has advanced considerably[2–6], and enables the effects of separation to be predicted for most circumstances, or to be avoided by suitable section design when other considerations permit. On the other hand, separation effects in nozzles have recently received relatively little attention, and advances seem possible by exploiting knowledge gained from research on aerofoils. This point is illustrated in the present note by considering one of the more striking effects of separation in nozzle flows, namely that on shock position.

2. Factors determining the shock position in a nozzle

Consider a convergent-divergent nozzle operating with constant inlet total pressure, and across which the pressure ratio is adjusted by altering the exit pressure. If the exit pressure is reduced, a shock wave moves down-stream in the divergent part of the nozzle, and ahead of the shock the pressures are independent of exit pressure, and determined only by the nozzle geometry. As the shock moves downstream, the static pressure p_1 immediately upstream thus follows a locus (Fig. 1(a)) depending on the nozzle shape. Similarly the pressure p_2 immediately downstream of the shock will follow a locus which, in the absence of boundary layer effects, is related to the p_1 locus by the equations for a normal shock. Downstream of the shock, the pressure rises as the subsonic stream expands in the divergent nozzle, until the exit pressure is reached.

Referring to Fig. 1(*a*), suppose that pressure p_e is applied to the nozzle exit, then the shock position is determined by drawing upstream from p_e the curve representing the pressure distribution in the subsonic part of the flow until it strikes the p_2 locus. Now suppose that the rate at which the nozzle diverges is increased, as illustrated in Fig. 1(*b*). The pressures p_1 will be reduced and, again in the absence of boundary-layer effects, the pressures p_2 will be raised. The shock position for a given value of p_e thus lies farther downstream, a tendency

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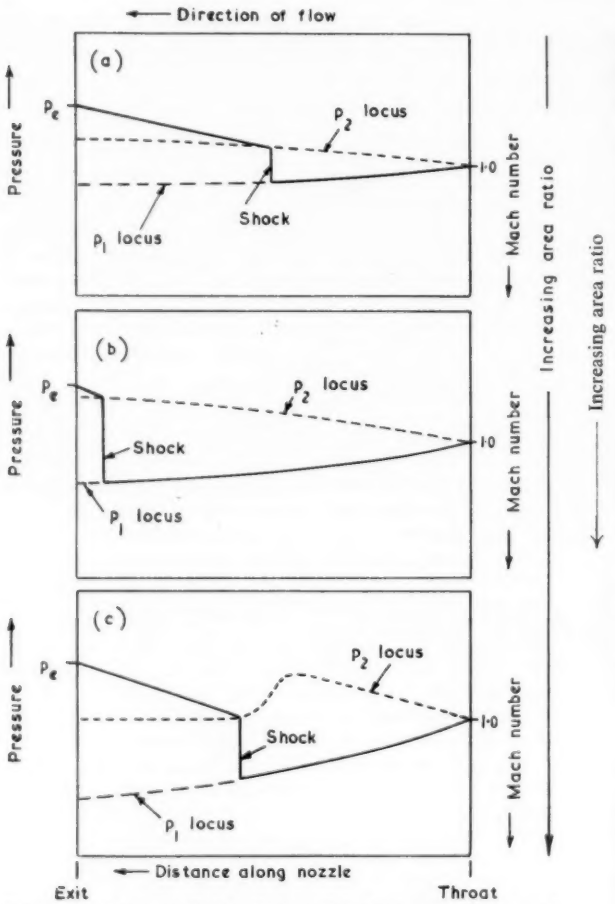

FIGURE 1. Pressure distributions and loci of pressures p_1 and p_2 immediately upstream and downstream of the shock for nozzles of different area ratio with the same inlet pressure, and exit pressure p_e.

which is strengthened by the increased pressure gradient downstream of the shock associated with the more rapid divergence of the subsonic stream. Thus, if boundary-layer effects can be ignored, it is to be expected that the shock position for a given overall pressure ratio moves downstream as the rate of divergence of the nozzle increases.

Provided that the shock is not so strong that it provokes boundary-layer separation, it would be expected from experience with aerofoils[3] that the above conclusion will not be altered by the presence of the boundary layer on the nozzle wall. During its downstream motion in the nozzle the shock may, however, become strong enough to separate the boundary layer. The pressure rise through the shock will then be greatly modified as illustrated by the shape of the p_2 locus in Fig. 1(*c*) which is typical[2] for a turbulent boundary layer. The result is that, once the divergence of the nozzle has become large enough to produce shock-induced separation, the shock position for a given exit pressure lies farther upstream than if separation were absent. There will, of course, be some change in the pressure gradient downstream of the shock due to the occurrence of separation, and this also affects the shock position (*see* Refs. 1-6).

3. An Experimental Demonstration of the Effect of Separation on Shock Position

The considerations outlined above suggest that if the rate

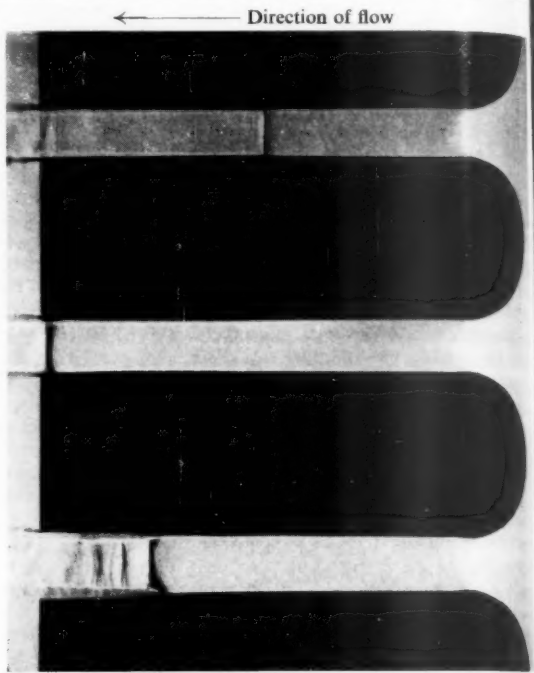

FIGURE 2. Schlieren photograph showing the shock-wave positions in three nozzles operating simultaneously at the same overall pressure ratio.

of divergence downstream of the throat of the nozzle is increased, the shock position for a given overall pressure ratio will at first move downstream, and then upstream after the shock becomes sufficiently strong to produce appreciable separation effects. To demonstrate this, three nozzles were arranged to operate simultaneously with identical conditions at entry and exit. The walls of the nozzles were straight downstream of the throats, and the area ratios were chosen to give exit Mach numbers of approximately 1·1, 1·2 and 1·4 for fully-developed supersonic flow. Transition to turbulent flow was fixed near the nozzle entries by distributed roughness, and, under these conditions, shock-induced separation would be expected[1, 2] to be absent throughout the first and second nozzles, but to occur during the passage of the shock through the third.

A schlieren photograph of the flow is reproduced in Fig. 2, and it is seen that, as predicted, the shock position is at first moved downstream by increase of divergence, but is subsequently displaced upstream after separation has occurred.

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A Subjective Experiment with Helicopter Noises

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INTRODUCTION

Following upon an experiment on the subjective effects of jet engine noise[1] we have recently undertaken a similar experiment, this time on the subjective aspects of helicopter noise. The purpose of the earlier experiment was to determine the reliability of various methods of rating based on spectrum analysis, so far as comparisons between jet- and piston-engined aircraft are concerned. The main objective of the present experiment was to find if these methods are applicable to the pulsating types of noise characteristic of helicopters.

EXPERIMENTAL METHOD

The general form of the experiment followed quite closely upon that carried out during the 1959 Farnborough Air Show[1]. As before, recorded sounds were used, in the form of two test tapes, identical save that the internal order of each pair of sounds was reversed on the second, and different groups of subjects were asked to judge whether one sound of a pair was "louder" than the other or whether it was "more disturbing." The instructions were recorded on two tapes separate from the test tapes and were played before them. One of the instruction tapes contained the word "louder" and the other the words "more disturbing." Each was paired in turn with each of the test tapes. Thus, four different series of judgments were obtained. Each group of listeners, however, heard only one of the four and was unaware of the alternative forms of the test.

The test tapes consisted of 50 paired comparisons arranged in a pseudo random order. Each sound was 4 seconds long and had starting and finishing transients approximately 0·1 *s* long produced by cutting the master tape at a very acute angle.

The order of one of the test tapes was as shown in Table I.

The other tape was constructed in the same order, namely *BA5, AD3, DB1, CB4* . . .

In Table I, the letter symbols refer to the five aircraft sounds listed below and the number following the pair of letters is a code denoting the relative levels of the two sounds identified by the letters. The five sounds were:

A	Bristol 171 Helicopter	Hover
B	Westland S55 Helicopter	Take-off
C	Fairey Rotodyne	Take-off (with tip-jet propelled rotor)
D	Fairey Rotodyne	Fly past (turbo-props)
E	Boeing 707/120 jet aircraft	Climb

Sound *E* was a copy of the tape used in the earlier experiment and was included as a common point to allow combination of the data. The relative levels at which each pair of sounds was presented covered a range of 12 dB. about a datum. The datum levels corresponded roughly to the condition of equal loudness, and were arrived at by trial listening experiments. Level 1 represents the first sound increased by 6 dB., paired with the second sound decreased by 6 dB, *i.e.* $XY1$ means $X+6$ with $Y-6$. Similarly $XY2$ means $X+3$ paired with $Y-3$; $XY3$ means X with Y; $XY4$ means $X-3$ with $Y+3$; and $XY5$ means $X-6$ with $Y+6$.

The purpose of using two test tapes with reversed internal order was to minimise the "reversal effect," that is to say the tendency in aural comparisons, to judge the last sound heard as the greater. By associating equal numbers of subjects with each tape and amalgamating the results, this effect is practically cancelled out.

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TABLE I

1	*AB1*	11	*EA1*	21	*AC3*	31	*BD2*	41	*EB4*
2	*DA3*	12	*BC3*	22	*CD5*	32	*EA4*	42	*CD1*
3	*BD5*	13	*CE5*	23	*AB4*	33	*CE1*	43	*DE3*
4	*BC2*	14	*AC2*	24	*BD1*	34	*EB3*	44	*DA2*
5	*CE4*	15	*CD4*	25	*EA3*	35	*AC5*	45	*BD4*
6	*AC1*	16	*AB3*	26	*BC5*	36	*DE2*	46	*BC1*
7	*CD3*	17	*DA5*	27	*EB2*	37	*DA1*	47	*CE3*
8	*DE5*	18	*EA2*	28	*AC4*	38	*BD3*	48	*EB5*
9	*AB2*	19	*BC4*	29	*DE1*	39	*EA5*	49	*CD2*
10	*DA4*	20	*EB1*	30	*AB5*	40	*CE2*	50	*DE4*

The experiment was made in a moderately reverberant room, about 140 m^3 in volume, which was treated by partially lining one of the walls with absorbent wedges to reduce the reverberation time and to enable a more uniform distribution of sound to be achieved. Three loudspeakers were used with the same intention, and their outputs were adjusted until the sound spectra at differing seats were as nearly identical as possible, the maximum discrepancy, in terms of octave band analysis, amounting to about 5 dB. Thus, the uniformity of sound distribution was somewhat better than in the earlier experiment[1]. The spectrum of noise *E* could not, however, be exactly repeated.

The subjects were all members of the staff of the Laboratory, and numbered 570 in all. They were exposed to the sounds in groups of 10 and were placed in seats whose positions had been chosen by the tests mentioned above. In every trial exactly 10 people were used, to avoid possible variations in the distribution of sound in the room.

It might be of interest to note that out of 570 returned cards there were only 12 which were unusable in one way or another. This small portion (2·1 per cent, compared with the 1·4 per cent obtained with the general public at the 1959 Farnborough Air Show[1]), shows that audiences of non-specialists have no difficulty in making the judgments required of them.

ANALYSIS OF RESULTS

The sounds played in the experiment were analysed into $\frac{1}{3}$ octave bands using an RMS meter. From these measurements the overall sound pressure levels, loudness levels computed according to the methods of Stevens[2] and of Zwicker[3], perceived noise levels (*PN* dB.)[4] and frequency weighted sound level (*A* weighting)[5] were derived. The $\frac{1}{3}$-octave spectra of the sounds are shown in Figs. 1-5, which refer to the datum levels.

It had been anticipated that difficulty might arise in estimating the values of sound pressure level in the bands when the sound is of a fluctuating or "chuffy" character[6]. However, a careful analysis of the overall sounds on various meters (slow reading RMS, fast reading RMS, and peak) failed to show any marked periodicity at the "chuff" frequency for either of the two sounds, namely *A* and *C*, which appeared to the ear to have this character. This finding was confirmed when the peak meter (an oscilloscope) was preceded by various integrating circuits of time constant ranging from 0·2 *s* upwards. For the purpose of deriving the single-figure measures of noisiness and so on, the spectra must be determined at one instant of time. Since there were no apparent short-term fluctuations, this moment could be conveniently chosen as that corresponding to the maximum reading of the meter. The different meters reached their maxima at slightly

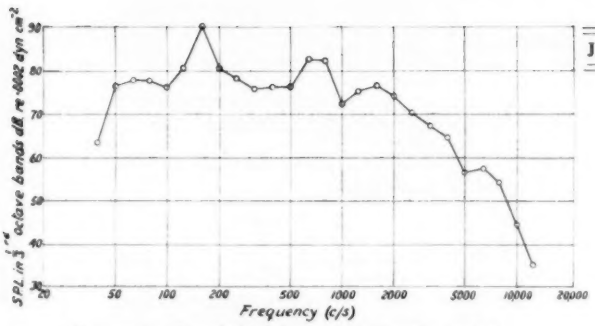

FIGURE 1. One-third octave spectrum of sound *A*.

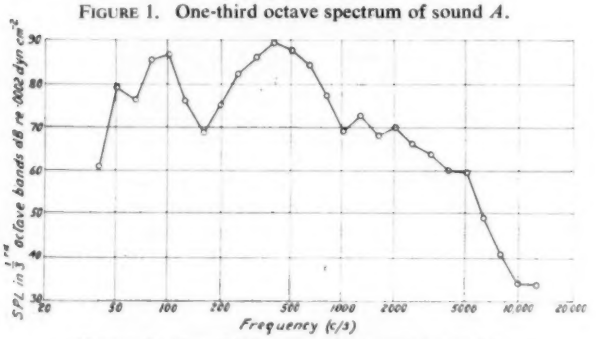

FIGURE 2. One-third octave spectrum of sound *B*.

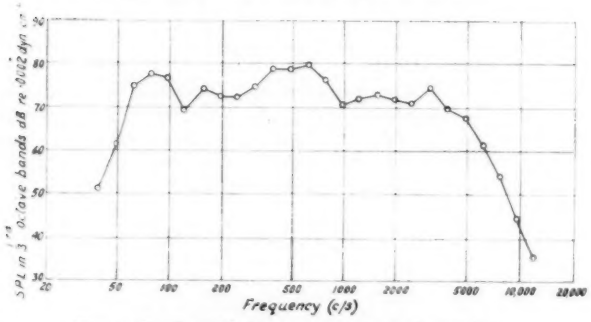

FIGURE 3. One-third octave spectrum of sound *C*.

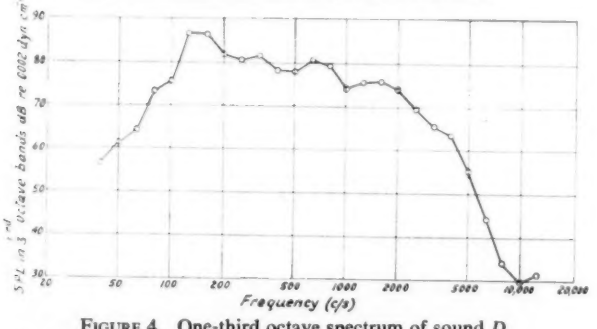

FIGURE 4. One-third octave spectrum of sound *D*.

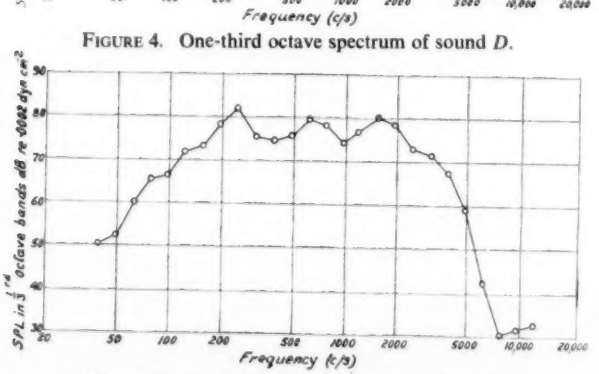

FIGURE 5. One-third octave spectrum of sound *E*.

TABLE II

Sound	*Overall sound pressure level* (dB. re 0·0002 dyn/cm²)
A	93·7
B	96·3
C	88·1
D	95·1
E	89·2

differing times on some of the noises, and the evaluation was therefore made for each; the results were barely distinguishable.

The peak meter has also been used to examine the sounds analysed into octave bands and it was found to be possible to detect "chuffiness" on Sound *C* at a frequency of about 10 c/s and amplitude about 6 dB. in the 1200–2400 c/s band. In other bands, and for the other noises such periodic variations were barely observable. It would raise many problems to take such effects into account in calculations of loudness level. For example, only RMS values satisfy the additivity principle, therefore there is no simple relationship between peak values in ⅓-octave bands and octave bands, and calculations based on these analyses would diverge. Moreover, the determination of peak values implies a time constant, and information is at present scanty on a suitable value to adopt.

Table II shows the mean levels presented to the subjects. These are the datum levels of the actual sounds in terms of slow RMS readings. They were chosen as high as possible consistent with the range of variation required and the power-handling capacity of the equipment available.

The results of the subjective experiments were evaluated by a form of probit analysis, determining the shift of each sound in each pair (relative to the appropriate datum levels) corresponding to the median observation. A typical example is shown in Fig. 6. The ordinate scale refers to the number code in Table I.

In Table III the median results so found are expressed in terms of sound pressure levels, and so on. Since the results emerged as shifts relative to datum levels for each of the 10 pairs of sounds, sound *A* has been arbitrarily pinned at the value shown in Table II to establish a reference. Having fixed *A*, each of the others could be arrived at in various ways by proceeding round the cycle *A-B-C-D-E*. A symmetrical solution, which minimises the distortion of the 10 subjective comparisons, was adopted, using the least-squares criterion.

TABLE III

	Sound	*Overall sound pressure level* (dB. re 0·0002) dyn/cm²)	*Sound Level A* (dB. re 0·0002 dyn/cm²)	*Loudness level* (*phons*)		*Perceived noise level* (*PN* dB.)
				Stevens	*Zwicker*	
At equal loudness	*A*	93·7	87·6	100·8	104·7	101·0
	B	96·8	91·2	102·8	105·7	103·4
	C	89·0	85·9	98·0	103·8	100·7
	D	96·3	89·4	101·9	106·0	102·2
	E	91·0	88·8	98·2	105·1	100·1
At equal disturbance	*A*	93·7	87·6	100·8	104·7	101·0
	B	98·0	92·4	104·0	106·9	104·6
	C	89·1	86·0	98·1	103·9	100·8
	D	97·7	90·8	103·3	107·3	103·6
	E	91·3	89·1	98·4	105·3	100·4

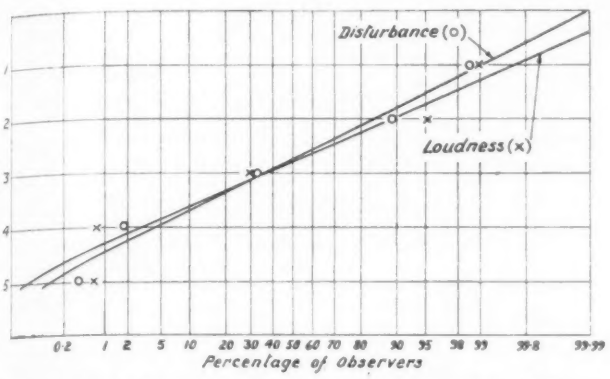

FIGURE 6. A typical example of subjective comparison results pair *EA*.

In this way, the corresponding entries for sounds *B*, *C*, *D* and *E* were obtained. The maximum distortion involved was 0·8 dB. (comparison of sounds *A* and *D* on the "disturbance" basis) and the average only 0·3 dB.

CONSISTENCY TESTS

A valuable check on the data is the consistency within each of the ten triads *A-B-C*, etc. For example, if we consider the sounds *A*, *B*, *C*, we should, by combining the results for the paired comparisons correctly, obtain zero for perfect closure. In other words, if we form the sum $AB - AC + BC$ the divergence from zero is an indication of the reliability of the data.

In Table IV the arithmetic mean is one formed by ignoring the sign of the deviations. The entries in Table IV should be viewed in relation to the standard error of the subjective comparisons. The latter were obtained from the curves of which Fig. 6 is an example, and were surprisingly uniform throughout the comparisons. The standard deviation was, on the average, 3·0 dB. corresponding to a standard error of about 0·2 dB. The closure of each triad might therefore be expected to agree to within $3 \times \sqrt{3} \times 0{\cdot}2$ dB., namely 1·0 dB., if we accept the "3 standard error" criterion. Most of the triangular consistencies are within this figure.

CONCLUSIONS

With the greatly varying character of the sounds, it is of value to compare the efficacy of the various methods of calculating loudness and disturbance. Table V shows, in summary form, the amounts by which the currently used measures of loudness and disturbance (Zwicker phons, Stevens phons, *PN* dB.) deviate from the ideal for these sounds. If these measures were perfect the values in Table V would be zero; no regard has been paid to the sign of the error. Overall sound pressure levels and sound levels with the *A*-frequency weighting are included for comparison. The values correspond to successive differences between rows in Table III. The final column in Table V is the signless average taken over all possible pairs of noises.

The conclusion is therefore that Zwicker phons are to be preferred for these comparisons, followed by *PN* dB., and then Stevens phons. This is so, whether we consider the signless mean, or the range of error; and whether the judgment is by loudness, or by disturbance. As between the evaluations of phons (Zwicker) and perceived noise levels (*PN* dB.), however, there is only a small advantage. It may be noted that sound level *A* predicts the subjective results as well as loudness level by Stevens' method.

TABLE IV

Triad	*Loudness*	*Disturbance*
ABC	−0·4	−0·4
ABD	−0·9	+0·8
ABE	−1·5	−1·1
ACD	+0·4	+1·7
ACE	−0·2	+0·7
ADE	−0·9	−1·8
BCD	+0·9	+0·5
BCE	+0·9	+1·4
BDE	−0·3	+0·1
CDE	−0·3	−0·8
Means (Arithmetic)	0·6	0·9
Means (Algebraic)	−0·2	+0·1

TABLE V

Criterion	*Method of assessment*	*Min.*	*Max.*	*Range*	*Mean*
Equal loudness	Phons (Zwicker)	0·4	2·2	1·8	1·1
	PN dB.	0·3	3·3	3·0	1·6
	Sound Level *A*	0·6	5·3	4·7	2·5
	Phons (Stevens)	0·2	4·8	4·6	2·7
	Overall s.p.l.	0·5	7·8	7·3	4·2
Equal disturbance	Phons (Zwicker)	0·4	3·4	3·0	1·8
	PN dB.	0·2	4·2	4·0	2·2
	Sound Level *A*	1·5	6·4	4·9	3·2
	Phons (Stevens)	0·3	5·9	5·6	3·3
	Overall s.p.l.	0·3	8·9	8·6	4·8

The entries in the "minimum" column do not refer to the same pair of noises in each case. On the other hand, the "maximum" values occurred in most cases in the comparison *BC*.

Referring to Table III, it will be noted that there was only a small difference in the mean judgments of the two groups of listeners. If one classes the two jet noises (*C* and *E*) together and compares the relative disturbance and loudness of these with noises *B* and *D* (one a piston, the other a turbo-prop), the difference amounts to 1·1 dB., in the sense that the jets are relatively more disturbing than they are loud. Noise *A* contained an appreciable high-frequency content, which was attributed to rotor swish; as regards relative disturbance and loudness judgments it could be classed with *C* and *E*.

ACKNOWLEDGMENTS

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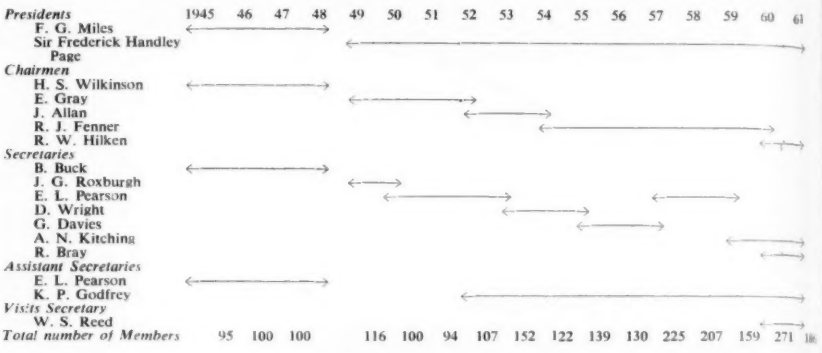
THE BRANCHES

The Reading Branch has seen two separate periods, first forming in 1945 with a break in 1948-49. The chart shows the office holders over the two periods and the membership.



Although Sir Frederick Handley Page has been President of the Reading Branch since 1949, and it was Handley Page (Reading) Ltd. which restarted the Branch in 1949, it was on the initiative of Miles Aircraft Technical School that the first formation was undertaken. This was in August 1945, and the Branch inaugural Meeting was convened by Mr. W. Evans of Miles Aircraft, Mr. F. G. Miles being the first President.

The Meeting was held at Woodley Aerodrome, to find support for the formation of a Branch to serve Miles Aircraft and surrounding factories and with R.Ae.S. approval, the Reading Branch became an official entity, with Mr. H. S. Wilkinson as Chairman and Mr. Buck as Secretary.

With Miles' wide range of aircraft types, it was perhaps appropriate that the first visit of the Branch was to an Air Pageant at White Waltham, organised by A.T.A. (Air Transport Auxiliary, for the younger members who may not remember) prior to its being disbanded. Reading then organised two Garden Parties of their own at Woodley in 1946 and 1947; Mr. Miles, as Branch President, was able to welcome Sir Frederick Handley Page as Society President, and also the representatives of the First Anglo-American Aeronautical Conference in 1947.

And dealing with firsts, the Branch took a cautionary outlook with their first lecture, by Group Captain Bandidt, on accident prevention. The title—"Attention to Detail."

After two and a half years, the Branch ceased activities with the close of Miles Aircraft, as it then was in 1948. There was a resurgence in later years—that of Miles Aircraft—and due to the efforts of Handley Page (Reading) Ltd., Reading Branch in 1949. Sir Frederick has continued as President since the beginning of the second formation, has given three lectures to the Branch and is to give another this coming Lecture Session.

The aerodrome at Woodley has a long association with the Branch, and even longer for many of its Members, for flying and aircraft construction date back there to 1929. Today it is the home of the Handley Page Herald. Handley Page and Reading have a shared history since 1949; support also comes from M/L Aviation of White Waltham, C. F. Taylor of Wokingham, Western Manufacturing Ltd. of Woodley, and a postal section covering most of the aeronautical industry in the area.

In other areas the Branch have paid visits to Vickers-Supermarine and Vickers Aircraft, Bristol, de Havillands, Saunders-Roe (including three visits in three years to the Princess Flying Boats) and jointly with the Coventry and Gloucester and Cheltenham Branches, to the College of Aeronautics at Cranfield.

Among current activities has been a "Flying Evening," when many Members were able to do some passenger flying, which places more than an academic interest in Branch activities. In a small way, there has also been a Garden Party with flying events, and it seems that a visit is now due to the Miles' segment of BEAGLE to complete the circle of historical association. As Mr. Peter Masefield gave the first Main Society Lecture at Reading in 1957, this should not be too difficult to arrange.

As this would appear to be a history of names, the Branch ask that special mention be made of the service of Mr. E. L. Pearson and Mr. K. Godfrey, who have each served on the Committee for ten years or so in various capacities.

Branch News

An item of exceptional interest from the Branches is from Weybridge, which has inaugurated an Anglo-American Conference Award for two Ex-Apprentices. The following is taken from the Official Notice:

"The Committee of the Royal Aeronautical Society, Weybridge Branch, has decided to sponsor a delegate from among recent ex-apprentices, and the Company has agreed to sponsor an additional delegate to accompany him. Candidates should be ex-apprentices who have, in the past four years obtained their Degree, Dip. Tech., H.N.D. or H.N.C. with endorsements in Aerodynamics or Aerostructures. They should also be members of both the Main Society and Weybridge Branch of the Royal Aeronautical Society.

The two successful candidates will be released with pay for the period of the Conference and the following expenses will be paid:—Conference Fee, Travelling Expenses, and Charges for functions which form part of the Conference.

It is intended that these awards should be made every fourth year when the joint conference is held in England."

The successful ones, to whom our congratulations, are:

R. Manning, an undergraduate apprentice until the autumn of 1957 in which year he obtained an Upper 2nd Class Honours Degree in aeronautical engineering at Southampton University. He spent the following two years studying at post-graduate level at the same University. He is now an operations engineer attached to the Military Aircraft Office.

J. W. Failes completed his engineer apprenticeship earlier in the year and took his Diploma in Technology in aeronautical engineering at Kingston Technical College. He was for three years chairman of the then Apprentice Club. He is at present a design draughtsman.—G. W-W.

Woodley Aerodrome—1931.

Graduates' and Students' Section

Graduate Training

The article by K.W.S. in the May Journal has thrown light on many of the thorny problems of Graduate training. As he asserts, the major problem experienced by the newly fledged graduate on entering Industry is his change of status from senior student to graduate apprentice.

The psychological aspects of this question are so acute that many graduates prefer to enter Industry as junior technicians rather than as graduate apprentices and so fail to gain any basic practical knowledge whatsoever.

As a means of alleviating this situation the following course of action is suggested for the prospective engineer on leaving school:

One year in Industry on the factory floor.
First year at University.
Summer vacation in Industry in a technical department.
Second year at University.
Summer vacation in Industry in a technical department.
Third year at University.
Six months in Industry in two technical departments.

By completing the year of practical experience *before* entering University, the change in status problem is minimised and the knowledge of industrial techniques so gained should greatly benefit the student at University.

The suggestion for the training of graduates within each department as outlined by K.W.S. in his article are to be applauded. One of the most demoralising occurrences which can befall the young technician on entering a technical department is to be handed a sheet of figures and told to plot a graph therefrom. After this procedure has been repeated a dozen or so times the graduate legitimately begins to wonder why he ever went to University. This often repeated happening usually occurs because the senior engineer involved feels he has no time to train students who anyway will only remain in his department two months. Section leaders should be made to recognise the fact that it is just as important for them to spend time coaching their junior staff, whether they be permanent or temporary, as it is for them to do their routine work. When the new arrival joins a section the senior engineer should explain the scope of duties of the section and its relative position within the overall organisation. An outline of the work the newcomer will be expected to do should be mutually agreed upon. This will obviously depend on the work in hand but should be planned to cover as many aspects of the section's work as possible. Such a programme would result in the student having a more complete understanding of the work with which each department is involved and also would result in a positive contribution to this work.

It would be interesting to hear from others who are going to be, or have been, "through the mill," and from those who are responsible for the training programme of young aeronautical engineers in the Industry.

The future of the British Aircraft Industry obviously depends on an increasing supply of well qualified engineers. If this demand is to be met, more emphasis will have to be placed on the training received by students and graduates within the Industry, as this early training is the basis upon which the young engineer builds his and the Industry's future.—W.G.W.

Any comments from Training Officers?—Ed.

Awards for Section Members

Earlier this year it was made known that the Council of the Society was unable even to consider awarding the Pilcher Memorial Prize due to a complete lack of entries. The resulting disappointment of the Section Committee was mentioned in the July Journal.

There are, in fact, a dozen Awards specifically for Graduate and Student Members of the Society, and we are publishing the details of these Awards here, in the hope of encouraging one or two of the three thousand members of the section to compete.

The awards are divided into three groups, the Prizes, the Scholarships and the Medals. The prizes are seven in number. They are awarded annually at the discretion of the Council. The first is the Pilcher Memorial Prize. This is for the most valuable paper *read* by a Graduate or Student during the previous year, at any meeting of the Society or the Branches. The second is the Usborne Memorial Prize for the best contribution to the Society's publications *written* by a Graduate or Student on some subject of a technical nature in connection with Aeronautics.

The other five prizes are awarded to the best student in the Aeronautical Departments of Cambridge University, Belfast, The Imperial College of Science and Technology, Queen Mary College, The University of Bristol, The University of Glasgow, The University of Southampton, the College of Aeronautics, Cranfield, and Northampton College of Advanced Technology.

Next, the Society's Scholarships. These are all awarded for post-graduate research or study in Aeronautics, and are tenable for one year. There is a possibility of an extension for a second year at the Council's discretion.

The Scholarships are:
The Charter Scholarship, The Edward Busk Studentship in Aeronautics and The Geoffrey de Havilland Memorial Scholarship.

The medals awarded to Graduates and Students are those of the N. E. Rowe Medals Competition. The two medals are awarded for the best lectures given before any Branch of the Society by a member of the Branch. The entrants for the first medal must be under twenty-one on the day of the lecture. The entrants for the other medal must be between twenty-one and twenty-six, again at the time of the lecture.

Each Branch may submit one entry for each Medal every year, and the lectures considered the most suitable are then delivered before an audience of Graduates, Students and representatives of the Council who act as adjudicators if necessary.

This list is a bare outline of the awards available and further details can be obtained from the Secretary of the Society at 4 Hamilton Place, or from Branch Secretaries.

It is very much to be hoped that the recent lack of entries for some of these awards has been due rather to ignorance of their existence than to lack of enthusiasm to compete.

Autumn Lectures and Visits

Members will be receiving the list of the Section's Autumn activities in the near future.

The first event in the Autumn programme will be a Film Show, in the Lecture Theatre, on 27th September at 7 p.m.

Visits

A visit has been arranged to the Esso Research Laboratories at Abingdon, Berks. on Wednesday afternoon, 20th September 1961. A most interesting visit has been promised, so members are urged to book a place immediately. Apply to the Hon. Visits Secretary, N. R. Craddock, 5 Oxleay Road, Harrow, Middx. (Tel. Pinner 3633).

The Section has been invited to visit the National Gas Turbine Establishment at Pyestock, Farnborough, Hants., in the near future. If sufficient people are interested, the Hon. Visits Secretary will arrange a date on a Wednesday afternoon. Everyone interested please apply to N. R. Craddock.

THE LIBRARY

Reviews

BOUNDARY LAYER AND FLOW CONTROL. VOLUME I. *Edited by G. V. Lachmann. Pergamon, Oxford,* 1961. 600 *pp. Illustrated.* 10 *gns.*

To its devotees, the phrase "boundary layer control" has a magic ring about it. It lays before them visions of perfection, prospects of unlimited efficiency, and fabulous rewards of commercial success. The editor of this book admits as much when, in his preface, he tells of it being "written by dedicated men for the use of dedicated men"; and this he evidently sees as the highest commendation.

But it does not always work in that way: enthusiasts are sometimes their own worst advocates and a team-ful of them needs strong captaincy. If therefore one has a criticism of this book, it leans more towards the editorial policy than towards the works of individual authors. The editor clearly decided at an early stage to collect a relatively large number of independent papers, and not to attempt any combinatorial editing. Your reviewer can only say, with what he hopes is a disarming frankness, that the result of this editorial policy is not to his liking.

Having said that, let him then go to applaud the appearance, at long last, of the first book devoted solely to a major branch of aerodynamics. It is long overdue —after all, the founder of boundary layers himself experimented with boundary layer control to strengthen his physical ideas. Perhaps the trouble has been that boundary layer conrol is a technological rather than a scientific field of study (if the reader grasps my meaning) and it is much more difficult to be permanently authoritative about hardware than about mathematics. What we all should have liked is, of course, an attempt at a co-ordinated definitive statement of the theory and practice of boundary layer control; and if that is asking for the moon, let us still hope, with the young President, that we have it before 1970!

This first volume starts with separate historical surveys for the four major Western countries, extending over some 140 pages. There is constant repetition of scientific ideas between these independent accounts and it is here that one regrets most the absence of a synoptic view. Nevertheless, for those who have been in the game, there is much interesting reading here (and fun, too, in identifying between the lines the claims as they are stated).

The rest of this volume is taken up with the problems of the prevention of separation, and of the increase in lift, both being considered only for subsonic flow. (The second of the two volumes will deal with low drag, and shock-induced separation.) Each section seems to be quite self-contained, and the treatments range from interesting overall accounts to detailed presentation of specific analytical methods. All the authors are well-known authorities and this is a real virtue of the book. Even the chapters on the Coanda effect and on a class of free-streamline flows—which are straightforward scientific papers making no concessions to their companions in this book—contribute a great deal to the interest of the book as a whole.

This review need not list in any detail the individual titles of the contributions. There is no obvious omission, unless it be that swept-back wings are considered explicitly in only one title. Therefore one finally wonders about the value of the book for the scientific world as a whole rather than for those dedicated men to whom the editor has aimed the book. And my doubts remain, that this presentation of the subject may fail to attract those who might otherwise have responded to the charms of boundary layer control.—BRYAN THWAITES.

METEOROLOGY FOR GLIDER PILOTS. *C. E. Wallington. John Murray, London,* 1961. 284 *pp. Illustrated.* 25*s.*

No sport depends so much on a science as does gliding upon meteorology. The glider pilot soon learns to control his propulsive unit, gravity, but his flight can be prolonged only if he can find rising air at frequent intervals. This skill he must acquire by practice based on a fairly wide meteorological knowledge. He must first understand the mechanisms by which energy from the sun is transferred into vertical currents, ranging from "thermals" on an otherwise calm day to vertical components in the jet stream. The glider pilot may find that the meteorologists know little about these vertical currents or have acquired knowledge too recently for it to be found in books. Although thermal upcurrents produce cumulus clouds and thus dominate our summer weather pattern, books on meteorology are very vague about these upcurrents. How do they start and from where? Is the rising air in chimneys or bubbles? Does it rotate? Is it warmer than the surrounding air? Most of these questions and many others are being answered only after collaboration between glider pilots and meteorologists.

Books were similarly vague until recently about the great vertical waves in the air which have carried gliders to over 40,000 ft. and have caused many aircraft to crash into mountains. The questions asked by the sailplane pilots and the information they have brought back to the meteorologists have gradually shed light on these obscurities.

C. E. Wallington is a symbol of this collaboration. He was nominated by the Meteorological Office to assist glider pilots with the forecasts they needed. He has become their respected friend and has now learned to fly sailplanes himself. It is not always easy for a professional to pass on his knowledge to keen amateurs, but Wallington has succeeded both in his briefings and now in his book. His style is easy and his hundreds of drawings, done with such meticulous care but perhaps too crowded, make reading pleasant.

The first part of the book is on general meteorology but gives special prominence to aspects vital to glider pilots such as convection and the afternoon sea breezes which, so often, destroy convection long before sunset. (Did you realise that sea breezes from Southend have been charted as far inland as Oxford?) Later chapters on Thermal Soaring Prospects and Wave Soaring are of more immediate use to soaring pilots but the whole book provides a first class introduction to meteorology for other pilots, yachtsmen and all with eyes for the drama of the weather. I hope that the title does not deter those who are not (yet) glider pilots from reading this excellent book.

Soaring has given so much pleasure to so many that it is sobering to reflect that if thermals had turned out to be of the order of 400 *inches* across, man could not have joined the birds in their pastime. It transpired, however, that thermals are around 400 *yards* across. I wonder why—and what luck!—ALAN YATES.

THE STABILITY OF MOTION. *N. G. Chetayev. Translated from the Russian by Morton Nadler. Pergamon, London,* 1961. 200 *pp.,* 60*s.*

This book is an exposition of the work of Lyapunov on the stability of motion. It should be intelligible to anyone equipped with an Honours degree in mathematics, a sound knowledge of Routh's "Advanced Rigid Dynamics" and a good deal of perseverence.

The foundation of the work is Lyapunov's basic

stability theorem, according to which the stability of a perturbed motion depends upon the existence of a sign-definite function whose time-derivative is either identically zero or oppositely sign-definite.

This theorem is applied to a variety of standard cases, including a study of the validity of conclusions on stability based upon the linear approximations to equations of motion.

The concluding chapters on transient and periodic motions contain valuable results for equations with time-dependent coefficients.

Throughout the book, the arguments and proofs, though complete, are considerably condensed in form. Worked examples are interspersed with the text, and each chapter concludes with a list of references, almost exclusively Russian. The publishers have thoughtfully made arrangements for the supply of translations "at a reasonable price."

The market for this book will inevitably be limited, a fact which partly accounts for the stiff price, as the publishers recognise in an apologetic note.—S. J. GARVEY.

MAGNETIC TAPE INSTRUMENTATION. *Gomer L. Davies. McGraw-Hill, London, 1961. 263 pp. Diagrams. 66s.*

The use of magnetic tape recording for scientific and engineering purposes, as distinct from entertainment, is now commonplace. There has, however, been a shortage of useful collected information on the problems particular to this kind of application. This book satisfactorily fills the gap, the author, for the most part successfully, steering a middle course between the hazards of attempting too much and achieving too little.

The subject matter covered includes every topic of importance. The treatment is almost entirely non-mathematical, the detailed theory being left to the authors of the many papers referred to in the chapter-by-chapter bibliographies. A fair amount of understanding of engineering and electronic principles is, however, assumed, and in view of this there are one or two passages which might have been omitted, the explanation of F.M. spectra, for example, in Chapter 3.

There are places, too, where the treatment seems in danger of deteriorating into a summary of results from the references, but these are few.

The chapters on Tape-Motion Irregularities, and Flutter and Skew Compensation are especially good; the author has clearly studied these topics thoroughly and holds the view that it is uneconomic to devote excessive time and money to the difficult task of eliminating skew and flutter when their effects may be compensated for with comparative ease.

For a book of this type some chapters are under-illustrated and in a few places the reader may feel that he would have been grateful for a little more numerical information, on limiting tensions and accelerations for instance in the chapter on Tape Transport Mechanisms.

These are small criticisms, however, and this book can be strongly recommended not only, as suggested on the dust cover, to potential users of magnetic tape equipment, but also to development engineers who find themselves for the first time engaged in this field of technology. For them it should prove an invaluable reference and guide. —G. H. STEARMAN.

NEW METHODS IN LAMINAR BOUNDARY-LAYER THEORY. *D. Meksyn. Pergamon, Oxford, 1961. 294 pp. Diagrams. 70s.*

Two topics of prime importance to prospective readers or purchasers of a book (and therefore, *a priori*, to a reviewer) are the ground which the author aims to cover and how successful he is in his aim.

The ground covered by the book under review appears to be limited, in that it consists mainly of a collection of Dr. Meksyn's own original contributions to laminar boundary-layer theory and, to a lesser extent, the theory of hydrodynamic stability. The book gives only scant attention to the contributions of other workers, particularly in the boundary-layer part. It follows that it is unlikely to satisfy those looking for a general introduction or for a reference book on the subject. On the other hand, for anyone who wishes to study Dr. Meksyn's own distinctive approach to the calculation of laminar boundary layers, the book is fairly comprehensive.

The question remains as to whether Dr. Meksyn has been successful in his aim, and here the reviewer has been somewhat disappointed. Although the discussion of the author's own method is much clearer than in the original papers, it is still not easy to see the field as a whole, since there is a lack of plan about the book after the first few chapters. Concerning the contributions of other workers, criticism could perhaps be levelled at the choice of material. For example, in discussing approximate methods of solving the boundary-layer equations, the author implies that Pohlhausen's method is the only one available, and makes no mention of the considerably improved methods due to Head, Stratford, Tani, Thwaites and others. Equally, Dr. Meksyn makes no mention of the many precise numerical solutions for particular pressure distributions.

In conclusion, this book appears to be of most value to those wishing to study Dr. Meksyn's own methods, but it is not easy reading.—N. CURLE.

DH. AN OUTLINE OF DE HAVILLAND HISTORY. *C. Martin Sharp. Faber and Faber, London, 1961. 419 pp. Illustrated. Appendices. 42s.*

For a long time Martin Sharp has been responsible for de Havilland's publicity and during that time he has produced a stream of fine quality material, all in the best of taste. He has during those years seen an enormous amount of the development of de Havillands through triumphs and setbacks.

There is probably no-one better qualified to record the history of this organisation which has progressed from the time when the small group struggled to keep the business alive just after the 1914-18 War through the ups and downs of the 1920s to the ultimate success with one of the world's most famous families of aeroplanes—the Moths, the Dragons and Rapides, the Comet racer, Mosquitos, Doves, Herons and Comets.

This is a fascinating story and it is well told. In fact it relates much more than the history of the company. It traces the life and work of Sir Geoffrey de Havilland from his first aeroplane built in Fulham, then his Farnborough days and the days with the Aircraft Manufacturing Company of George Holt Thomas to the time when DH became an aircraft manufacturer under his own name and all that followed.

The book contains more of the story of the men than the machines and this is as it should be. It is essential that records should be published of the small group of pioneers who had the faith and foresight to design, build and fly the first aircraft and then go on to establish the industry which has ensured our defence in time of war and contributed much to our economy in peace.

There is an abundance of published material on the men who built Britain's railways but relatively little on those who developed our aviation.

In spite of the attention given to DH himself and those who worked with him, Martin Sharp has managed to cram an incredible amount of other information into his book.

There are 168 illustrations and the long captions for these, together with the appendices, occupy 60 pages. Within these 60 pages is a mass of valuable reference material much of which I believe has not been published elsewhere. Included is a list of every DH aircraft and engine type with main details including the numbers built, details of outstanding flights made by DH aircraft and much else of value.

Later this year another author, with full assistance from de Havilland, is publishing a book detailing the

history of all DH aircraft from the D.H.1 to the present. Martin Sharp's book and this other still to be published should together constitute the most complete history of an aircraft manufacturer that has ever been produced. It would be nice to think that DH's example will be followed so that the entire British aircraft industry will be recorded for those born into a world in which aviation "has always existed."—JOHN STROUD.

SAINT-EXUPÉRY. *Marcel Migeo. Macdonald, London.* 1961. 335 *pp.* 30*s.*

Probably between 15 and 20 biographies of the famous French author-airman, Antoine de Saint-Exupéry, have now been published. This latest effort, by a pilot who knew Saint-Exupéry and who claims to have spent ten years writing this book, is probably the best so far—certainly it is the best this reviewer has read. While properly devoting his main attention to the philosophical aspect of his subject's writing, Mr. Migeo also succeeds in giving a considerably more convincing portrait of the man's character than any previous biographer—a portrait inevitably, alas, less attractive than that drawn by previous admiring writers. Indeed, the truth seems to be that, whatever his talents as an author and poet and whatever his appeal as a brilliant conversationalist, Saint-Exupéry was, in fact, a quite-exceptionally selfish, self-centred and unstable individual who made few friends during his lifetime.

It is possible to winnow out of this book, for the first time, a reasonably factual picture of Saint-Exupéry, the airman. Far from being a "great aviator" as has been claimed by most previous biographers—a claim, incidentally, repeated in the blurb on the dust jacket of this book—Saint-Exupéry is shown to have been the rather unreliable pilot which one might expect of somebody of his temperament. The picture of his flying career which emerges is of considerable interest.

He learnt to fly in 1921 on Sopwith 1½-Strutters at a civil flying school at Neudorf aerodrome, near Strasbourg, while doing his two years national service as a private in the air force. Having obtained his civil pilot's licence, Saint-Exupéry applied to become a military pilot and then completed his service flying training in North Africa and in France. On completing his national service, he became a second-lieutenant in the air force reserve and, returning to civil life, worked at various non-aeronautical jobs. During this period he kept himself in flying practice as a reservist at Orly.

In 1926 he joined the famous Latécoère Airline as a pilot at its main base at Montaudran aerodrome, near Toulouse, and it was from there that he first flew on the line through Spain to Morocco. Perhaps it was partly his temperamental unsuitability as an airline pilot, however, which led to his being made station superintendent (which apparently also meant acting as a relief pilot) at Juby, on the West African coast, in the following year. He remained at this remote desert outpost for nearly two years and, while there, must have shown real administrative ability because, after a brief return to France for leave and a navigation course at Brest, he was posted to Buenos Aires in 1929 as Managing Director of Aeroposta Argentina, the associate company of Aéropostale—which the Latécoère Airline became in 1927—which operated the far end of the French air route to South America.

During 15 months in South America, Saint-Exupéry seems to have done quite a lot of flying, in addition to his administrative duties. He returned to France in 1931 and was then posted to Port-Etienne in West Africa where he once again became an ordinary line pilot until Aeropostale failed financially in 1932. He then joined the Latécoère aircraft company as a test pilot, but did not stay with them long. After a frustrating period of unemployment, he joined Air France—which succeeded Aéropostale—in 1934 and was employed for a short time as a first officer on the flying boat service from Marseilles to Algiers. This did not last either and he was transferred to the public relations branch.

During the five years of peace which remained, Saint-Exupéry spent most of his time writing and on lecture tours. However, he also made several long distance flights in light aircraft, two of which ended in accidents. He was called up when War came in 1939 and served as a reconnaissance pilot during the "phoney war" and the Battle of France. After escaping to Algeria with his squadron, he was demobilised and returned to unoccupied France. Late in 1940 he went to the United States where he remained until the North African landings in 1943. He then rejoined his reformed squadron and, in 1944, was shot down over the Mediterranean while on a reconnaissance flight in a Lockheed Lightning. During a flying career lasting 23 years he is said to have accumulated some 7,000 hours as pilot.—PETER W. BROOKS.

PROGRESS IN AERONAUTICAL SCIENCES, Vol. 1. *Edited by A. Ferri, D. Küchemann and L. H. G. Sterne. Pergamon Press, Oxford,* 1961. 280 *pp. Diagrams.* 80*s.*

This is the first volume in a new series of specially commissioned review articles in the aeronautical sciences, but excluding propulsion and combustion, which are the subject of a separate series. The volumes will be published annually and are intended to provide the specialist reader with a concise survey of recent work and the general reader with an opportunity of acquiring information on recent developments in fields other than his own.

The actual papers, written as they are by acknowledged specialists, are surely of individual merit and of great interest to their own readership. But as a collection they are surprising. There is a seven page descriptive review "On the Principles of Aerodynamic Design," by E. C. Maskell and a 32 page one on "Structural Problems of Aircraft Pressure Cabins," by D. Williams. The remaining five papers, two in French and one in German, are much more specialised, generally longer, and deal with, broadly, aerodynamic subjects. They are:

R. Legendre—"Calcul des Profils d'Aubes pour Turbomachines Transsoniques." M. Fenain — "La Théorie des Ecoulements à Potentiel Homogène et ses Applications au Calcul Des Ailes en Régime Supersonique." E. Becker—"Instationäre Grenzschichten hinter Verdichtungsstossen und Expansionswellen." F. A. Goldsworthy—"On the Dynamics of an Ionized Gas." C. H. E. Warren and D. G. Randall—"The Theory of Sonic Bangs."

In a series such as this one would expect each volume *either* to cover one branch of aeronautics *or* to be a balanced mixture of papers drawn from each of the, say, half dozen major branches. But this book does neither and strikes one as a random collection, as regards length, subject matter, readership appeal and language. It is difficult to escape the feeling that this first volume is composed of the first seven papers available in the series and that these made a book of suitable size. However, this does not detract from the value of the individual contributions.—E. C. P.

Additions to the Library

Aerial Photographs in Geologic Interpretation and Mapping. Richard G. Ray. U.S.G.P.O., Washington. 1960. 230 pp. Illustrated. 18s. Geological Survey (Professional Paper 373), which considers the use of aerial photographs to obtain qualitative and quantitative geologic information, and instrument procedures employed in compiling geologic data.

Aerofoil Sections. Dr. Friedrich Wilhelm Riegels. Butterworth, London. 1961. 281 pp. Illustrated. £10. *To be reviewed.*

Air Force Combat Units for World War II. Maurer Maurer (*Editor*). U.S.G.P.O., Washington, 1961. 506 pp. 22s. 6d. A product of the U.S.A.F. Historical Division, Air University, Department of the Air Force, the

book gives a potted history of Groups, Wings, Commands and Air Forces. Identification Badges are illustrated. Here is an indication of an awareness on the part of a service department for the need for such books. Obtainable through H.M.S.O.

Airport Drainage. U.S. Federal Aviation Agency. U.S.G.P.O., Washington. 1960. 71 pp. 2s. 8d. Five sections deal with General (characteristics and purposes); Hydrology; Grading Criteria; Design of Drainage System; Methods of Construction. Standards are, of course, American. Obtainable through H.M.S.O.

The Astronauts. The Seven Astronauts of Project Mercury (American). Cassell, London. 1961. 110 pp. Illustrated. 25s. The story of the flight and preparation for Project Mercury told, in a chapter each, by the seven selected American astronauts who underwent two years of rigorous training for America's first manned space flight. A final chapter gives Commander Shepard's own account of his flight, which makes excellent reading. This is the first of two volumes, the second of which will be written by one of the seven astronauts chosen to encircle the earth.

Bio-Assay Techniques for Human Centifruges and Physiological Effects of Acceleration. P. Bergeret (*Editor*). Pergamon Press, London. 1961. 176 pp. Illustrated. 70s. International aeromedical experts have contributed the 15 papers of this AGARD volume, edited by a member of the Aero Space Medical Panel. All are concerned with the biomedical effects of acceleration.

Development of High-Temperature Strain Gauges. J. W. Pitts and D. G. Moore. . N.B.S. Monograph 26. U.S.G.P.O., Washington. 1961. 20 pp. Illustrated. 20 cents. Summarises work done at the National Bureau of Standards in a research programme sponsored by the U.S. Navy and Air Force. Includes an investigation of the properties of high-temperature strain-gauge materials, the development of high-temperature strain gauges, and the development and evaluation of high-temperature strain-gauge cements.

Escape and Survival: Clinical and Biological Problems in Aerospace Medicine. P. Bergeret (*Editor*). Pergamon Press, London. 1961. 117 pp. 45s. A collection of 13 papers contributed by international experts and published for AGARD; edited by a member of the Aero Space Medical Panel, the papers include escape and ejection at high and low altitude, parachutist's spin problem, arctic survival training, medical problems of air crew, the choice of gas mixture for breathing in high performance aircraft, animal and man in the space environment, and simulation techniques.

Flight Briefing for Pilots. Volume I. A. H. Birch and A. E. Bramson. Pitman & Sons Ltd., London. 1961. 182 pp. 15s. *To be reviewed.*

General Dynamics of Vibrations. Y. Rocard. Crosby Lockwood & Son Ltd., London. 1960. 522 pp. 80s. A translation of a book now in its third edition in France. The difference from other volumes on the same subject is in its much wider outlook, covering applications to mechanical and civil engineering, the acoustic of electronic and radio engineering, instruments, and pure physics. Based on a course of lectures at the Sorbonne and at the Ecole Normale.

Hydrodynamics. A Study in Logic, Fact and Similitude. Second Edition. Garrett Birkhoff. Oxford University Press, London. 1961. 184 pp. 42s. A complete revision of a book first published ten years ago as an analysis of the foundations of hydrodynamics, with special reference to two aspects of fluid mechanics: the complicated relation between theory and experiment, and applications of symmetry concepts. A new chapter has been added on turbulence.

Meteor Science and Engineering. D. W. R. McKinley. McGraw-Hill, London. 1961. 309 pp. Illustrated. 97s. Summarises the major observational and theoretical developments in meteor science and embraces the spatial history of meteor particles and the effects they create in the upper atmosphere. Explains the astronomical and physical aspects of meteor studies to the engineer and the non-astronomical scientist, while describing the practical applications of meteors to the astronomer and the pure scientist. Includes radio techniques, contributions from optical research and a study of the practical application of the forward-scattering properties to commercial and military communications systems.

Operation Mercury. An Airman in the Battle of Crete. M. G. Comeau. Kimber Pocket Editions, London. 1961. 160 pp. 2s. 6d. A paperback. The author describes the attempts of the Air Force to keep up air attacks with obsolete aircraft and from makeshift airports and his escape from Crete after its capture.

The Orion Book of Balloons. Charles Dollfus. Orion Press, New York. 1961. 108 pp. Illustrated. $6·95. *To be reviewed.*

Project Hummingbird: A Technical Summary and Compilation of Characteristics and Specifications on Steep Gradient Aircraft. U.S. Federal Aviation Agency. U.S.G.P.O., Washington. 1961. 161 pp. Illustrated. 15s. 9d. A report, the second in the "Project Hummingbird" series, summarising the state of the art in Steep-Gradient Aircraft development, including planning guidance, methods of achieving steep-gradient flight and possible civil applications and problem areas. Appendices contain specifications and performance figures of machines and engines of this type throughout the world.

Tables for the Compressible Flow of Dry Air. E. L. Houghton and A. E. Brock. Edward Arnold Ltd., London. 1961. 64 pp of tables. 12s. 6d. Contains a new set of tables for the parameters of isentropic, Prandtl-Meyer expansive, Rayleigh, Fanno, plane normal and plane oblique shock flows. The Mach number range is 0 to 4 with $\gamma = 1{\cdot}403$. The aim is to provide a low-priced collection of tables that the student may use throughout his studies and retain for use in his subsequent career as a practising engineer.

The Tercentenary Celebrations of the Royal Society of London. Sir Harold Hartley (*Editor*). The Royal Society, London. 1961. 142 pp. Illustrated. Contains a paper by Sir Arnold Hall on "Trends in aeronautical science and engineering."

A Torch to the Enemy: The Story of the Devastating Fire Raid against Tokyo—March 10th 1945. Martin Caidin. Ballantine Books Inc., New York. 1960. 160 pp. Illustrated. 2s. 6d. The material is drawn either from official records or personal accounts. There is no attempt at sensation, apart from what is in the facts.

Reports

AERODYNAMICS

BOUNDARY LAYER *see also* CONTROLS
THERMO-AERODYNAMICS

A background of the problems of boundary layer research. H. Schlichting. AGARD Report 253. *April* 1960.
The following items are treated to some extent: stability and transition, turbulent boundary layers, three-dimensional boundary layers, boundary layer control, boundary layers in hypersonic flow. The unsolved boundary layer problems for incompressible flow are reviewed.—(1.1).

Effect of roughness on transition in supersonic flow. E. R. Van Driest and C. B. Blumer. AGARD Report 255. *April* 1960.—(1.1.2.4).

Review of the effect of distributed surface roughness on boundary-layer transition. A. L. Braslow. AGARD Report 254. *April* 1960.
A discussion of the transition phenomena associated with distributed roughness, a correlation of three-dimensional roughness effects at both subsonic and supersonic speeds, and the effect of laminar boundary layer stability as influenced by heat

transfer, pressure gradients, and boundary-layer control on the sensitivity of laminar flow to distributed roughness.—(1.1.2.4).

Effects of unit Reynolds number nose bluntness and roughness on boundary layer transition. J. L. Potter and J. D. Whitfield. AGARD Report 256. *April* 1960.
Factors affecting transition and the effects of unit Reynolds number and very small degrees of leading edge bluntness are discussed. A means of estimating the effect of roughness on boundary layer transition is suggested.—(1.1.2.4).

The effect on profile drag of randomly distributed low-intensity roughness. W. S. Coleman. AGARD Report 257. *April* 1960.
The effect of randomly distributed roughness on the behaviour of the boundary layer is discussed in terms of the turbulent spots generated by the excrescences. Functions defining the intermittency factor for turbulence at any cross-section of the boundary layer are obtained, first, from the kinematical properties of spots, and second, from the transition theory of Emmons. The two approaches are found to lead to substantially the same result. In the light of this analysis, the influence of the roughness on wing profile drag is considered.—(1.1.2.1 × 1.10).

Experimental investigation on boundary layer suction by series of slits and holes. W. Wuest. AGARD Report 258. *April* 1960.
The development of laminar and turbulent boundary layers with pressure gradient on various permeable test walls (filter paper, slits, holes, perforations) has been studied in the low-turbulence wind-tunnel. The behaviour of wall-stress, dissipation and the different boundary layer parameters is deduced from the measurements.—(1.1.5.1).

Boundary layer development in supersonic shear flow. R. H. Rogers. AGARD Report 269. *April* 1960.—(1.1.2.4).

Boundary layer separation in the presence of heat transfer. G. E. Gadd. AGARD Report 280. *April* 1960.—(1.1.4.4 × 1.9.1).

On the calculation of steady boundary layers for continuous suction, with discontinuously variable suction velocity. W. Rheinboldt. N.A.S.A. T.T. F-29. March 1961.—(1.1.5.1).

"Similar" three-dimensional boundary layers. T. Geis. N.A.S.A. T.T. F-30. March 1961.—(1.1.1.1).

Effect of nose bluntness on transition for a cone and a hollow cylinder at Mach numbers 1.41 *and* 2.01. *W. J. Monta* et al. *N.A.S.A. T.N. D-717. April* 1961.—(1.1.2.4).

COMPRESSIBLE FLOW *see also* INTERNAL FLOW
LOADS
STABILITY AND CONTROL
THERMO AERODYNAMICS
TESTING AND INSTRUMENTS

External-drag estimation for slender conical ducted bodies at high Mach numbers and zero angle of attack. E. F. Valentine. N.A.S.A. T.N. D-648. March 1961.
A method of estimation of the external drag of conical ducted bodies at high Mach numbers has been developed. Charts which facilitate the computations are presented. Samples of the variation of drag characteristics with Mach number and with geometric parameters illustrate how the method may be utilised.—(1.2.3.1).

Predicted shock envelopes about two types of vehicles at large angles of attack. G. E. Kaatari. N.A.S.A. T.N. D-860. April 1961.
Methods based on oblique- and normal-shock relationships and the continuity of mass flow through suitably chosen volume elements between the shock and a body were developed to predict shock envelopes about blunt nosed and/or conical vehicles such as are being considered for atmosphere entry. Comparisons of measured shock envelopes with predicted values for range $M = 3$ to 15 were presented for vehicles at high angles of attack.—(1.2.3.2 × 8.2).

Head-on interaction of oblique shock waves. S. Mölder. U.T.I.A. T.N. 38. *Sept.* 1960.—(1.2.3.2).

Possibilités et limites actuelles de la théorie des écoulements hypersoniques. J. P. Guiraud. O.N.E.R.A. Pubs. 99. 1961.—(1.2.3.1).

CONTROLS

Some exploratory jet-flap tests on a 60-*deg delta wing. J. Williams and A. J. Alexander. R. & M.* 3138. 1961.—(1.3.4 × 1.10.2.2).

Water tunnel experiments on a Zap-flapped suction aerofoil. R. H. Wickens et al. *N.R.C. Report L.R-294. Dec.* 1960.—(1.3.4 × 1.1.5.1 × 1.10.2.1).

Flight investigation using variable-stability airplanes of minimum stability requirements for high-speed, high-altitude vehicles. N. M. McFadden. N.A.S.A. T.N. D-779. April 1961.
Particular emphasis was placed on operation at negative static margins, resulting in the determination of minimum levels of stability and damping required for adequate control. Brief tests of the limits of controllability in the lateral-directional mode were also made.—(1.3.2 × 1.8.2.1 × 1.8.1.1).

FLUID DYNAMICS *see also* TESTING AND INSTRUMENTS
HYDRODYNAMICS

The normal impingement of a circular air jet on a flat surface. P. Bradshaw and E. M. Love. R. & M. 3205. 1961.—(1.4.3.13).

Analysis of multipoint-multitime correlations and diffusion in decaying homogeneous turbulence. R. G. Deissler. N.A.S.A. T.R. R-96. 1961.—(1.4.2).

A one-dimensional analysis of magnetohydrodynamic energy conversion. R. G. Deissler. N.A.S.A. T.N. D-680. March 1961.—(1.4.4 × 27.7).

Atomic recombination in nozzles: methods of analysis for flows with complicated chemistry II. K. N. C. Bray and J. P. Appleton. A.A.S.U. Report 178. *May* 1961.—(1.4 × 1.5.1.4 × 32.1).

Some aspects of free shear-layer instability and sound emission. E. Mollö-Christensen. AGARD. Report 260. *April* 1960.
The relative importance is discussed of instability fluctuations and turbulence as noise sources in a jet. Ways of detecting sound emission from instability waves in a jet are described and some of the problems associated with supersonic disturbances in shear layers—from which the sound emission may be very intense—are discussed.—(1.4.2 × 5.6 × 27).

Ein thermo-gasdynamisches Diagramm für Luftplasma. O. Lutz. D.F.L. Bericht 145. 1961. *(In German.)*
The diagram applies to air plasma with temperatures up to 100,000°K. Some examples illustrate the versatility of the diagram.—(1.4.4).

INTERNAL FLOW *see also* FLUID DYNAMICS
INSTRUMENTS AND EQUIPMENT
AIRCRAFT OPERATION
TESTING AND INSTRUMENTS

Calculations of the one-dimensional nonequilibrium flow of air through a hypersonic nozzle—interim report. W. G. Vincenti. A.E.D.C.-T.N.-61-65. May 1961.—(1.5.1.4 × 1.2.3.1 × 22).

LOADS *see also* THERMO-AERODYNAMICS
WINGS AND AEROFOILS

Force and pressure tests of two elliptic ogive body shapes at Mach numbers 5, 6 *and* 8. *J. L. Burk. A.E.D.C.-T.N.-61-49. April* 1961.—(1.6.1).

Wind-tunnel investigation of the effects of wing bodies, fences, flaps, and a fuselage addition on the wing buffet response of a transonic-transport model. E. S. Cornette. N.A.S.A. T.N. D-637. April 1961.—(1.6.3 × 33.1.1).

Loads induced on a flat-plate wing by an air jet exhausting perpendicularly through the wing and normal to a free-stream flow of Mach number 2·0. *J. J. Janos. N.A.S.A. T.N. D-649. March* 1961.—(1.6.1 × 1.2.3 × 8.2 × 33.1.1).

Surface pressure distributions with a sonic jet normal to adjacent flat surfaces at Mach 2·92 *to* 6·4. *R. W. Cubbison* et al. *N.A.S.A. T.N. D-580. Feb.* 1961.—(1.6.1 × 1.2.3 × 8.2 × 33.1.1).

PERFORMANCE *see also* STABILITY AND CONTROL

Low-speed investigation of the effects of large wing-sideslip angles on the aerodynamic characteristics of two arrow-wing-fuselage arrangements. T. G. Gainer. N.A.S.A. T.N. D-656. Feb. 1961.

An investigation of two methods proposed to reduce the high sinking speeds and improve the landing characteristics of low-aspect-ratio hypersonic aeroplanes. For one model the wing was pivoted on the fuselage to angles of wing sideslip from 0° to 90°. For the other model, the wing was fixed to the fuselage and the wing and fuselage were yawed together to sideslip angles from 0° to 90°.—(1.7.1×1.8.1.2).

Nomographic solution of the momentum equation for V.T.O.L.-S.T.O.L. aircraft. H. H. Heyson. *N.A.S.A. T.N. D-814. April* 1961—(1.7×1.8.0.1×5).

STABILITY AND CONTROL *see also* CONTROLS
PERFORMANCE
TESTING AND INSTRUMENTS
AIRCRAFT
EXTRA ATMOSPHERIC
TECHNOLOGY

The lateral response of airplanes to random atmospheric turbulence. J. M. Eggleston and W. H. Phillips. *N.A.S.A. T.R. R-74.* 1960.
The power spectra of the lateral motions of an aeroplane flying through continuous random isotropic turbulence are derived. Random variations of gust velocities across the span and along the fuselage are considered. A simplified method is presented in which the gust velocities are represented as rolling gusts, yawing gusts, and side gusts. A sample calculation procedure is presented for obtaining the response of the aeroplane in each degree of freedom.—(1.8.2.1×33.1.1).

A wind-tunnel investigation of a transonic-transport configuration utilizing drag-reducing devices at Mach numbers from 0·20 to 1·03. D. L. Loving. *N.A.S.A. T.N. D-636. March* 1961.
Modifications to the model were forward fuselage additions and special wing bodies. Other components and changes investigated included an empennage, a wing-tip body, wing fences, wing trailing-edge flaps, horizontal tail settings, and wing dihedral angle. The investigation was made at angles of attack from −5° to 15·4°, sideslip angle of −5°, and Reynolds numbers from $0{\cdot}5\times10^6$ to $1{\cdot}9\times10^6$ based on the wing mean aerodynamic chord.—(1.8.1.2×1.8.2.2×1.2.2).

Low subsonic-speed static stability of right-triangular-pyramid and half-cone lifting reentry configurations. G. M. Ware. *N.A.S.A. T.N. D-646. Feb.* 1961.
The effect of various modifications such as base extensions, nose incidence, and ridge-line shape on lift-drag ratios and static stability was studied.—(1.8.0.2×25.2).

Some effects of nose bluntness and fineness ratio on the static longitudinal aerodynamic characteristics of bodies of revolution at subsonic speeds. W. C. Hayes and W. P. Henderson. *N.A.S.A. T.N. D-650. Feb.* 1961.—(1.8.2.2).

Investigation of the static stability characteristics of two stages of a three-stage missile at a Mach number of 4·00. A. B. Carraway et al. *N.A.S.A. T.N. D-651. March* 1961.
An investigation to determine the aerodynamic characteristics of two stages of a Trailblazer II configuration. Included was the determination of the effect of fin cant, fin size, and length of the transition between stages.—(1.8.0.2×25.2).

Investigation of the static longitudinal and lateral stability characteristics of a 0·10-scale model of a three-stage configuration of the Scott research vehicle at Mach numbers of 2·29, 2·96, 3·96 and 4·65. L. S. Jernell. *N.A.S.A. T.N. D-711. March* 1961.—(1.8.1.2×1.8.2.2).

Effect of ratio of jet area to total area and of pressure ratio on lift augmentation of annular jets in ground effect under static conditions. K. W. Goodson and J. H. Otis. *N.A.S.A. T.N. D-720. March* 1961.
An investigation in which the ratio of jet area to total area ranged from 1·00 to 0·02 and the pressure ratio from about 1·04 to 1·95 was made in a static test room with use of the compressed-air facilities. Several configurations with centre jets were tested through an angle-of-attack range to determine the pitching-moment characteristics.—(1.8.2.2×3.13×27).

Ground interference effects. R. O. Schade. *N.A.S.A. T.N. D-727. April* 1961.—(1.8.0.1×3.12).

A method for obtaining the nonlinear aerodynamic stability characteristics of bodies of revolution from free-flight tests. D. B. Kirk. *N.A.S.A. T.N. D-780. March* 1961.—(1.8.2.1×1.12.2).

Investigation of the longitudinal characteristics of a large-scale jet transport model equipped with controllable thrust reversers. D. H. Hickey et al. *N.A.S.A. T.N. D-786. March* 1961. (1.8.2.2×1.7.3×5.6).

Non-linear effects in the longitudinal dynamics of a lifting vehicle in a circular orbit. R. S. Rangi. *U.T.I.A. T.N. 40. October* 1960.—(1.8.2.1×8.2×22.2).

THERMO-AERODYNAMICS *see also* BOUNDARY LAYER

An experimental technique to measure heat transfer data on a blunt body at M=3·98. L. Broglio and C. Buongiorno. *AGARD Report 284. April* 1960.—(1.9.1).

Shielding of partially reflecting stagnation surfaces against radiation by transpiration of an absorbing gas. J. T. Howe. *N.A.S.A. T.R. R-95.* 1961.
The laminar compressible boundary layer in the two-dimensional and axisymmetric stagnation regions has been analysed to show the effects of the injection of a radiation absorbing gas on the incident radiation field, on enthalpy profiles, and on heat transfer to the vehicle surface. Heat-transfer results are presented and compared with those for the unshielded case. The required absorption properties of the foreign gas are determined and compared with properties of known gases.—(1.9.1×1.1.1.4).

Surface pressures and heat transfer on unswept blunt plates in helium at high Mach numbers. J. G. Marvin. *N.A.S.A. T.N. D-688. March* 1961.
Data were obtained on a flat plate at zero angle of attack with various amounts of leading-edge bluntness at Mach numbers of 12.5 and 14.7. Measured heat-transfer coefficients are compared with values predicted across the laminar boundary layer. Shock-wave shapes were represented by a form of the blast-wave analogy.—(1.9.1×1.6.1×1.2.3.2).

A theoretical analysis of effects of ablation on heat transfer to an arbitrary axisymmetric body. R. T. Swann and J. South. *N.A.S.A. T.N. D-741. April* 1961.—(1.9.1).

Ballistic range measurements of stagnation-point heat transfer in air and in carbon dioxide at velocities up to 18,000 feet per second. L. Yee et al. *N.A.S.A. T.N. D-777. March* 1961.
A new technique for measuring heat-transfer rates in free flight in a ballistic range is described. Measurements of the stagnation-point heat-transfer rates in air and in carbon dioxide at velocities up to 18,000 feet per second are given and the results compared with the experimental results obtained in shock tubes and with the results of theory.—(1.9.1×1.12.1.3).

WINGS AND AEROFOILS *see also* BOUNDARY LAYER
CONTROLS

Pressure measurements at the centre of a 40° swept back wing with R.A.E. 101-10 sections at zero incidence and transonic speeds. J. E. Rossiter. *C.P. 542.* 1961.
The range of investigation included speeds from $M_0=0{\cdot}5$ *to* 1·22 at zero wing incidence at a Reynolds number of 1·3 million based on the wing chord. For some of the tests, boundary layer transition was fixed ahead of the 10 per cent chord line on the wing.—(1.10.1.2×1.6.1).

Pressure distributions at zero lift for delta wings with rhombic cross sections. E. Eminton. *C.P. 525.* 1960.
The linearised theory of thin wings is used to calculate pressure distributions over delta wings with rhombic cross sections. A DEUCE programme has been written for the calculation and some of the results are compared with those of slender thin wing theory.—(1.10.1.2×1.6.1).

An analysis of the flow over two 45-deg swept-back wings at high subsonic speeds, and comparison with theory. R. Cook. *R. & M. 3194.* 1961.
A comparison of pressure distributions obtained from theory and from wind-tunnel tests on two swept-back wings. The experimental flow conditions and patterns are briefly discussed insofar as they are relevant to the comparisons.—(1.10.0.2).

HELICOPTER AERODYNAMICS

Hovering characteristics of a rotor having an airfoil section

designed for flying-crane type of helicopter. J. P. Shivers. N.A.S.A. T.N. D-742. April 1961.
Static-thrust performance data are presented for a full-scale rotor having a N.A.C.A. 63_2A015 aerofoil thickness distribution in combination with a N.A.C.A. 230 mean line for blade tip Mach numbers from 0·35 to 0·67.—(1.11.3).

TESTING AND INSTRUMENTS *see also* STABILITY AND CONTROL
THERMO-AERODYNAMICS

Effects of sting-support diameter on the base pressures of an elliptic cone at Mach numbers from 0·60 *to* 1·40. *L. S. Stivers and L. L. Levy. N.A.S.A. T.N. D-354. Feb.* 1961.
Pressures were measured on the base of an elliptic cone model having a cross-section thickness-to-width ratio of 1/3 and a plan form semi-apex of 15°. The measurements were made for five sting configurations, including that of effectively removing the sting for angles of attack from −2° to +20° at a constant Reynolds number of 1·4 million, based on the length of the model.—(1.12.1×1.2.2).

Near-field and far-field noise measurements for a blowdown-wind-tunnel supersonic exhaust jet having about 475,000 *pounds of thrust. W. H. Mayes* et al. *N.A.S.A. T.N. D-517. April* 1961.—(1.12.1.3×5.3).

A technique for obtaining hypervelocity impact data by using the relative velocities of two projectiles. W. H. Kinard and R. D. Collins. N.A.S.A. T.N. D-724. Feb. 1961.
A 22-calibre light-gas gun is used to launch projectiles toward targets fired from a 37-millimetre powder gun. Results of several preliminary firings are included for an impact-velocity range from 12,050 ft. per sec. to 21,850 ft. per sec.—(1.12.1.3).

An investigation of a device to oscillate a wind-tunnel air-stream. C. F. Reid and C. G. Wrestler. N.A.S.A. T.N. D-739. April 1961.
Measurements were made of the magnitude and phase relationship of an air stream oscillation generated in a wind-tunnel test section at low speeds in air and at Mach numbers to 0·80 in Freon 12, over a Reynolds number range of $1·78\times10^6$ to $3·82\times10^6$ per foot, and at frequencies to 20 cps. Tests were also made of the frequency response of a 60° delta semi-span wing with a conically cambered leading edge to illustrate how the system may be applied.—(1.12.1.3).

Hot-wire heat-loss characteristics and anemometry in subsonic continuum and slip flow. F. W. Boltz. N.A.S.A. T.N. D-773. Feb. 1961.
Three sizes of tungsten wire were tested in operating conditions covering wide ranges of speed and density. A general heat-loss expression was obtained from an analysis of the data, including factors to account for the effects of wire aspect ratio (ratio of length to diameter), compressibility, slip flow, and temperature loading.—(1.12.6.3×1.4).

Theoretical light-gas gun performance. W. B. Stephenson. A.E.D.C.-T.R.-61-1. May 1961.
One-dimensional, unsteady flow theory of an ideal gas is reviewed as it applies to guns and ballistic model launchers. The method of characteristics is developed for the general case including chambrage and finite chamber volume. Results for helium as a propellant are given from which the required chamber size can be determined. The launch velocity for combinations of launch tube and chamber geometries is computed assuming no friction nor heat loss and an evacuated bore.—(1.12.1.3×1.2.3.1).

Damping measurements with a sting-supported bearing-pivot dynamic balance. C. J. Welsh et al. *A.E.D.C.-T.N.-61-52. May* 1961.
Results of damping-in-pitch tests of a flared-afterbody re-entry shape. Measurements using a sting-supported bearing-pivot system were made at $M_\infty=8$ and over an amplitude range up to about 11°.—(1.12.4×1.8.2.2).

An assessment of readout errors encountered in radio telemetry from gun-launched hypervelocity projectiles. M. K. Kingery and P. L. Clemens. A.E.D.C.-T.N.-61-58. May 1961.
Recent progress in the development of radio telemetry instrumentation for use in an altitude simulating, aeroballistic range is discussed. The sources of error in the telemetered data are evaluated theoretically, and supporting experimental data are presented. An in-flight pressure telemeter calibration technique and static compression tests are described. Errors arising out of fluctuations in carrier frequency and telemeter sensitivity changes are analysed.—(1.12.6×18).

Design of the recoil system for the 4 *in.* × 7 *in. hypersonic shock tube. A. K. Roberts. U.T.I.A. T.N.* 42. *Oct.* 1960.—(1.12.1.3×1.2.3.2).

Velocity measurements in the University of Southampton hypersonic gun tunnel. G. E. Merritt. A.A.S.U. Report 172. *April* 1961.
A method of measuring flow velocity by observing the propagation of a cylindrical shock wave produced by a long (1·6 in.) spark discharge is described. Results are given of measurements made in air at a Mach number of approximately eleven using the University of Southampton hypersonic gun tunnel. Stagnation temperatures, over a range of initial conditions, have been calculated from the velocity results, an allowance being made for the caloric imperfection of the air.—(1.12.1.3×1.5.1.4).

The measurement of unsteady pressures in wind tunnels. E. J. Davis. AGARD Report 169. *March* 1958.—(1.12.5×1.12.1).

AIRCRAFT

See also AERODYNAMICS—FLUID DYNAMICS
STABILITY AND CONTROL
AIRCRAFT OPERATION
FLIGHT TESTING

A preliminary study of V./S.T.O.L. transport aircraft and bibliography of N.A.S.A. research in the V.T.O.L.-S.T.O.L. field. Langley Res. Center. N.A.S.A. T.N. D-624. Jan. 1961.—(3.12×5.1×30.1).

Aerodynamic characteristics of propeller-driven V.T.O.L. aircraft. R. H. Kirby. N.A.S.A. T.N. D-730. March 1961.—(3.12×1.8.2.1).

Induced interference effects on jet and buried-fan V.T.O.L. configuration in transition. K. P. Spreemann. N.A.S.A. T.N. D-731. March 1961.—(3.12×1.8.2.2).

Review of basic principles of V./S.T.O.L. aerodynamics. R. E. Kuhn. N.A.S.A. T.N. D-733. March 1961.—(3.12×27).

Handling qualities experience with several V.T.O.L. research aircraft. J. P. Reeder. N.A.S.A. T.N. D-735. March 1961.—(3.12×13.2).

Effects of geometric variations on lift augmentation of simple-plenum-chamber ground effect models. E. E. Davenport. N.A.S.A. T.N. D-756. April 1961.—(3.13).

Operational technique for transition of several types of V./S.T.O.L. aircraft. F. J. Drinkwater. N.A.S.A. T.N. D-774. March 1961.
The primary items considered are longitudinal trim changes during the transition, stability, stalled flow during descending transitions, and the flexibility of the transition procedure of each type of aircraft.—(3.12×5×1.8.2.1).

DESIGN AND CONSTRUCTION

Mechanical properties of pneumatic tires with special reference to modern aircraft tires. R. F. Smiley and W. B. Horne. N.A.S.A. T.R. R-64. 1960.
The principal topics discussed are tyre vertical-force-deflection characteristics; lateral, fore-and-aft, and torsional spring constants; footprint-area properties; relaxation lengths; rolling radius; cornering force, cornering power, self-aligning torque, and pneumatic caster for yawed rolling conditions; effects of wheel tilt; and tyre radial growth under the influence of centrifugal forces.—(4.2.2.3×5.3).

Some recent studies in structural dynamics of rotor aircraft. G. W. Brooks and M. A. Silveira. N.A.S.A. T.N. D-737. March 1961.
The studies include the determination of the forces and moments at the hubs of various rotor configurations, the control of the natural frequencies of rotor blades by the use of multiple flapping hinges or flex-joints, the mechanical instability of rotors with inclusion of additional degrees of freedom in the rotor support, and the effect of stiffness and damping on the gyroscope whirling instability of propellers.—(4.4×33.1.1).

AIRCRAFT OPERATION

See also AERODYNAMICS—FLUID DYNAMICS
PERFORMANCE
STABILITY AND CONTROL
TESTING AND INSTRUMENTS
AIRCRAFT
DESIGN AND CONSTRUCTION

Similarity of near noise fields of subsonic jets. W. L. Howes. N.A.S.A. T.R. R-94. 1961.
Similarity relations for frequency-pass-band, as well as overall, time-averaged pressure fluctuations outside a jet are derived and tested using experimental data.—(5.6).

Vertical accelerations encountered by aircraft on agricultural operations. R. T. Sewell. N.R.C. Report L.R.-304. April 1961.—(5.4.1×33.1.1).

Electric spark ignition in carbon-vane fuel pumps. J. A. Campbell et al. *N.A.S.A. T.N. D-589. Feb.* 1961.
An experimental study of the electric spark ignition hazard of carbon-vane fuel pumps.—(5.3).

Noise considerations in the design and operation of V./S.T.O.L. aircraft. D. J. Maglieri et al. *N.A.S.A. T.N. D-736. April* 1961.
Available propulsion-system noise data have been applied to the problems of design and operation of V./S.T.O.L. aircraft. In particular, considerations have been given to minimising adverse community reaction in operations between airports and to minimising detection due to noise for special missions.—(5.6×3.12).

Survey of altitude-measuring methods for the vertical separation of aircraft. W. Gracey. N.A.S.A. T.N. D-738. March 1961.
An evaluation of altitude-measuring methods based on measurements of gravity, acceleration, atmospheric pressure and density, cosmic-ray and magnetic-field intensities, capacitance, and radio and sound-wave propagation is presented. Each of the methods is evaluated primarily for the high-speed, high-altitude cruise condition. Estimates are given for the over-all errors of pressure-measuring systems which incorporate various types of limited-range and full-range instruments.—(5.3).

Random deviations from cruise altitudes of a turbojet transport at altitudes between 20,000 and 41,000 feet. W. Gracey and J. A. Shipp. N.A.S.A. T.N. D-820. April 1961.—(5.3).

Über ein neues Verfahren für die Prüfung der Luftdurchlässigkeit und der elastischen Eigenschaften von Fallschirmgeweben. H-D Melzig. D.F.L. Bericht 146. 1961. (*In German.*)—(5.3×1.5.1.3).

AIRPORTS

Etude de la répartition des contraintes sous les dalles reposant sur le sol: fondations, routes, pistes d'aérodrome. G. Scheuch. Pubs. Sc. et Tech. N.T. 96. 1961. (*In French.*)—(6.1).

EXTRA ATMOSPHERIC TECHNOLOGY

See also AERODYNAMICS—COMPRESSIBLE FLOW
LOADS
STABILITY AND CONTROLS
AVIATION MEDICINE
ELECTRONICS
INSTRUMENTS AND EQUIPMENT

Details of the flight of the "Vostok." Pravda 25th April 1961. *R.A.E. Lib. Trans.* 948. *May* 1961.—(8.2).

Optical observation of artificial earth satellites. N.A.S.A. T.T. F-11. Feb. 1961.

A collection of Russian articles, originally published in bulletin form, which deal primarily with methods used in determining the orientation of satellites. Included are articles pertaining to estimation of the variation of brightness of a satellite and determination of the orientation of the axis of rotation, using the satellite's known light curve. Related material, tabular and otherwise, is included.—(8.2).

A study of the positions and velocities of a space station and a ferry vehicle during rendezvous and return. J. M. Eggleston and H. D. Beck. N.A.S.A. T.R. R-87. 1961.—(8.2).

Considerations affecting satellite and space probe research with emphasis on the "Scout" as a launch vehicle. J. Posner. N.A.S.A. T.R. R-97. 1961.
Payload design and packaging, environmental tests, launch facilities, tracking and telemetry requirements, data acquisition, processing and analysis procedures, communication of information, and project management are discussed. Particular emphasis is placed on the "Scout" as a launching vehicle and the geometry of the "Scout" as well as its flight capabilities and limitations are described. Although oriented toward the "Scout" vehicle and its payload capabilities, the information given is sufficiently general to be equally applicable to most space vehicle systems.—(8.2).

Vanguard I satellite structure and separation mechanism. J. T. Shea and R. C. Baumann. N.A.S.A. T.N. D-495. March 1961.—(8.2×33.2.3.6).

Long range planning for space transportation systems. H. H. Koelle. N.A.S.A. T.N. D-597. Jan. 1961.
Trends in space transportation cost for earth-orbital, earth-lunar, and earth-planetary missions for the next decade are given, based on typical programmes.—(8.2).

Survey of characteristic velocity requirements for two-impulse transfers between circular and coplanar exterior elliptical orbit with exposition of local and overall optimum solutions. R. Silber. N.A.S.A. T.N. D-600. March 1961.
Coplanarity is assumed for the three orbital planes. Departure from the circular orbit is tangential. There is no restriction on the point of arrival at the elliptical orbit.—(8.1×22.2×26).

Artificial earth satellites and successful solar probes 1957-1960. *W. H. Stafford and R. M. Croft. N.A.S.A. T.N. D-601. March* 1961.
Included, in chronological order of the launchings, are descriptions of launching conditions, scientific experiments and accomplishments, and results of orbital measurements for each satellite or probe. Tables giving orbital data at various epochs during the life of each satellite; graphs of perigee and apogee altitudes versus date—period versus date; photographs of the satellites, probes and their launching vehicles, and other illustrations provide the most complete data available on each mission.—(8.2).

Determination of the required number of randomly spaced communication satellites. F. V. Bennett et al. *N.A.S.A. T.N. D-619. Jan.* 1961.
An investigation for determining the minimum number of passive satellites required to provide given percentages of communication time between any two ground stations is given with a sample application.—(8.2×18.1).

Landing characteristics and flotation properties of a reentry capsule. V. L. Vaughan. N.A.S.A. T.N. D-653. Feb. 1961.—(8.2×33.1).

An instrument to measure the solar constant from a satellite. R. A. Hanel. N.A.S.A. T.N. D-674. April 1961.—(8.1×18×32.2×11).

Discussions of solar proton events and manned space flight. K. A. Anderson. N.A.S.A. T.N. D-671. March 1961.
Two papers which deal with the prediction of solar beam events and the radiation hazard in space that results from them.—(8.1×8.2×9).

Study of systems using inertia wheels for precise attitude control of a satellite. J. S. White and Q. M. Hansen. N.A.S.A. T.N. D-691. April 1961.
Various possible inertia wheel systems are examined for suitability for precise satellite attitude control; three of the systems, which appear more promising than the others, are analysed in detail using the Orbiting Astronomical Observatory as an example.—(8.2×1.8.1).

Analog simulation of a pilot-controlled rendezvous. R. F. Brissenden et al. *N.A.S.A. T.N. D-747. April* 1961.
A simulator investigation of the controls and instruments required for the rendezvous of a space ferry with an orbiting space station in the presence of various initial conditions and

with ranges up to 50 miles. A human pilot controlled a fixed-base simulator in six degrees of freedom. A single rocket and reaction attitude controls were assumed.—(8.2×1.8.0.1).

Proceedings of meeting on problems and techniques associated with the decontamination and sterilization of spacecraft. 29th June 1960, *Washington, D.C. Ed. J. Posner. N.A.S.A. T.N. D-771. Jan.* 1961.—(8.2×9).

A preliminary study of a solar-probe mission. D. W. Dugan. N.A.S.A. T.N. D-783. April 1961.—(8.2×33.2.3.6).

Precision orbits of 413 *photographic meteors. L. G. Jacchia and F. L. Whipple. Smith. Cont. Astro. Vol.* 4, *No.* 4. 1961. —(8.1).

Observations of simulated meteors. R. E. McCrosky. Smith. Cont. Astro., Vol. 5, *No.* 4. 1961.—(8.1).

Orbital elements of meteors. G. S. Hawkins and R. B. Southworth. Smith. Cont. Astro., Vol. 4, *No.* 3. 1961.—(8.1).

AVIATION MEDICINE

See also EXTRA-ATMOSPHERIC TECHNOLOGY

First planning conference on biomedical experiments in extra-terrestrial environments. Held under the auspices of the N.A.S.A., Washington, D.C., 20th June 1960. *N.A.S.A. T.N. D-781. Feb.* 1961.—(9×8.2).

ELECTRONICS

See also EXTRA-ATMOSPHERIC TECHNOLOGY
INSTRUMENTS AND EQUIPMENT

The Javelin spike antenna; radiation patterns and voltage standing-wave ratio. R. R. Ford. N.A.S.A. T.N. D-565. Jan. 1961. —(11×8.2).

A very low frequency (V.L.F.) synchronizing system. C. H. Looney. N.A.S.A. T.N. D-669. Feb. 1961.—(11×18.1).

FLIGHT TESTING

See also AIRCRAFT

The X-15 research program. De. E. Beeler. AGARD Report 289. *Oct.* 1960.—(1.3.3×3.6×13.2).

A model-controlled autopilot for an airborne V.T.O.L. simulator. D. F. Daw and L. V. Ursel. N.R.C. Report L.R.-302. Feb. 1961.
To establish valid handling qualities requirements for V.T.O.L. and S.T.O.L. aircraft a need exists for a simulator which adequately simulates the dynamic response and environment of the vehicle under consideration. To this end a variable stability helicopter is proposed. This report outlines how a model-controlled auto-pilot may be used to vary the characteristics of a helicopter, enabling simulation of aircraft having a wide variety of dynamic response characteristics.—(13×18×3.12).

The flight testing of aircraft weapon systems. R. P. Dickinson. AGARD Report 287. *Oct.* 1960.
The flight testing of the airborne elements of the weapon system is dealt with for air-to-air weapons—guns, unguided rockets, guided weapons, and for air-to-ground weapons—unguided rockets, free falling bombs, guided bombs. The report is a broad survey amplified, where appropriate, by some detailed test techniques. The assessment is taken through the stages of cockpit, engineering, aerodynamic and auto control, armament loading and carriage, navigation up to the zone of operation, through the attack phase and finally to impact accuracy. The process of assessment is summarised by a diagram.—(13×25).

Dyna Soar research objectives. F. R. Anderton. AGARD Report 291. *October* 1960.
The flight regime of the Dyna Soar from which data will be obtained is presented in comparison with current manned space projects. The development of the glider through ground testing and research is outlined and areas in which significant technical advances will be made pointed out. The flight test programme is described with reference to specific test objectives.—(13×3.3).

FUELS AND LUBRICANTS

Investigation of stability test for refrigerator oils. L. Gardner et al. *N.R.C. Report M.P.-20A. March* 1961.—(14.2).

HYDRODYNAMICS

An experimental investigation of cavitation inception in the rotor blade tip region of an axial flow pump. A. B. Mitchell. C.P. 527. 1961.—(17.1).

The acceleration of water drops by an airstream of constant relative velocity. D. C. Jenkins. C.P. 539. 1961.
A method is suggested for estimating drag coefficients of water drops when the relative air speed is sufficient to cause distortion of the drops. The results have been used to calculate the acceleration of water drops down vertical ducts designed to give constant air speed relative to the drops.—(17.1×1.4).

Experimental investigation of a high-speed hydrofoil with parabolic thickness distribution and an aspect ratio of 3. *K. W. Christopher. N.A.S.A. T.N. D-728. March* 1961.—(17.1).

INSTRUMENTS AND EQUIPMENT

See also AERODYNAMICS—TESTING AND INSTRUMENTS
EXTRA-ATMOSPHERIC TECHNOLOGY
ELECTRONICS
FLIGHT TESTING

A low-resolution unchopped radiometer for satellites. R. A. Hanel. N.A.S.A. T.N. D-485. Feb. 1961.—(18.1×8.2).

Microwave reflectivity of deposited aluminium films for passive relay communications. W. F. Cuddihy and L. H. Shreve. N.A.S.A. T.N. D-664. Feb. 1961.—(18×11).

Eight-level pulse-height analyzer for space physics applications. U. D. Desai et al. *N.A.S.A. T.N. D-666. Jan.* 1961.
A scintillation spectrometer for the study of low-energy particles in space is discussed.—(18.1×8.2).

MATERIALS

See also FATIGUE
STRUCTURES—THEORY AND ANALYSIS

Mechanism of the oxidation of nickel and chromium alloys. D. V. Ignatov and R. D. Shamgunova. N.A.S.A. T.T. F-59. March 1961.
The principal methods of investigating the oxidation process of metals and alloys in gaseous media at increased and high temperatures (400°-1050°) are described. The main results of experimental works on the investigation of the oxidation kinetics and on the structure and composition of oxide films are given. Modern theories of the oxidation of metals and alloys are reviewed, and the possibility of using them to explain the oxidation mechanism of Ni-Cr alloys is considered.—(21.2).

The effect of repeated stressing on the behavior of lithium fluoride crystals. A. J. McEvily. N.A.S.A. T.R. R-91. 1961. —(21.3).

MATHEMATICS

See also AERODYNAMICS—INTERNAL FLOW
STABILITY AND CONTROL
EXTRA-ATMOSPHERIC TECHNOLOGY
MISSILES
SCIENCE—GENERAL

MISSILES

See FLIGHT TESTING

NAVIGATION

See EXTRA-ATMOSPHERIC TECHNOLOGY

POWER PLANTS

See AERODYNAMICS—FLUID DYNAMICS
STABILITY AND CONTROL
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MATERIALS

REFERENCE LITERATURE

See AIRCRAFT

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EXTRA-ATMOSPHERIC TECHNOLOGY

STRUCTURES

LOADS *see* AERODYNAMICS—LOADS
STABILITY AND CONTROL
DESIGN AND CONSTRUCTION
AIRCRAFT OPERATION
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THEORY AND ANALYSIS *see* EXTRA ATMOSPHERIC TECHNOLOGY

THERMODYNAMICS

See MATERIALS